ACTA UNIVERSITATIS SZEGEDIENSIS

ACTA MINERALOGICA–PETROGRAPHICA

TOMUS XIX. FASC. 2.

SZEGED, HUNGARIA
1970

ACTA UNIVERSITATIS SZEGEDIENSIS

ACTA MINERALOGICA–PETROGRAPHICA

TOMUS XIX. FASC. 2.

SZEGED, HUNGARIA
1970

Redigit

GYULA GRASSELLY

Edit

Institutum Mineralogicum, Geochimicum et Petrographicum
Universitatis Szegediensis de Attila József nominatae
Szeged, Táncsics Mihály u. 2.

Nota

Acta Miner. Petr., Szeged

Szerkeszti

GRASSELLY GYULA

Kiadja

a József Attila Tudományegyetem Ásványtani, Geokémiai és Kőzettani Intézete
Szeged, Táncsics Mihály u. 2.

Kiadványunk címének rövidítése

Acta Miner. Petr., Szeged

ACTA UNIVERSITATIS SZEGEDIENSIS

ACTA MINERALOGICA–PETROGRAPHICA

TOMUS XIX.

SZEGED, HUNGARIA
1969/1970

CONTENTS

70-3510 — Szegedi Nyomda

DEVELOPMENT OF EARTH SCIENCES IN HUNGARY DURING THE LAST QUARTER OF CENTURY*

G. PANTÓ

If we consider the last phase of development of the — at least ten — fundamental sciences, main objective of which is the Earth and common intention is a better understanding of its matter involved in past and future changes, it is apparent, that they got clustered under a common name, "*geonomy*", but in the last ten years. Actually this newly coined denomination (van BEMMELEN) covers much more than a new aggregation of earth sciences; it is not merely a new frame but rather a new scheme of closer and more efficient integration. Each branch of geo-sciences got in the course of these 25 years rid of the descriptive priming phase of its development, during which stiffened formalism and conservativism on the side of the "old" branches, while struggle for the rank of independent science at the youngsters prevented contemplation in a wider sphere. An open-minded interest for the neighbour's results, initiation of multilateral research enterprises is a symptom of the last decade's earth science development. But just these led to the conquest of interdisciplinary "no man's lands" and serve most efficiently the combined elucidation of common basic phenomena. The "geonomic" results of the joint earth science enterprises assure a close and living contact between fields and divisions of geonomy implying mutual assimilation and common evaluation of each other's achievements, in other terms a very broad scientific integration. It is probably not exaggerated to state that the last 25 years' common efforts enabled us to lay back an important section of the path leading to establish a standing and organic geonomic world concept.

Difficulties are inherent not only to the utmost magnitude (10^{15} km^3 calculated but until the solid Earth's surface) of the object, but in the diversities of its scientific approach and processing of relative data. The ten major constituent sciences of geonomy reflect essentially two main research attitudes:

1. examination (measurement) of material behaviours in a given moment,
2. geochronological scrutiny for detecting and dating of material changes occured during the 5.5 billion years geologic past.

* Lecture delivered on the Silver Jubilee of the institution of Provisional Government and National Assembly in Debrecen, 21 December, 1944.

The primary stage was in each case the *"static"* determination of material characteristics (effects) and this has been extended secondarily according to a *"dynamic"* aspect towards recording of temporal changes. It is just this second way of investigating and reasoning, which marks the conspicuous upswing of geo-sciences in the last two decades. At the same time, this way of reasoning was the ferment securing their common, rapid advance in our days.

The veteran among Earth's sciences is geology forwarding since its earliest, descriptive days *(geognosy)* the overall picture on processes inducing changes and rearrangements inside and on the surface of the globe, deciphering their nature and importance by areal survey and establishing, later on improving, their chronological sequence with endless care.

Besides the technically afforded leap — both in depth and in height — of the sphere of observation, it is the fruitful co-operation with fellow-sciences which rendered turning of its methods from descriptive-speculative to exact-inductive.

Geophysics and geochemistry appear some 200 years later as limitary offshoots (as physics and chemistry applied to the Earth) and their acceptance as independent sciences has been retarted to the present century. Among its pioneering discoveries figure those of ROLAND EÖTVÖS on the high accuracy determination of local variations in the intensity of gravity field. Attaining of independence was, however, unfortunately coupled with fortified demarcation, decline of immediate contacts between the geophysicists carrying out infinitely precise measurements, thinking but in figures and CGS-units, the geochemist detecting chemical composition of constituents of the Earth down to microgram accuracy and the "only" qualitatively reasoning geologist.

The lack of contact between the "statically" and "dynamically" minded scientists and/or even their growing antagonism excluded fruitful reciprocal action between geodesy operating with an "unchangeable" topography and geology emphasizing permanent transformations; between mineralogy-petrography immersed into meticulous description entangled by a severe typology and geology tracing but large scale processes and interactions. Hydrology and meteorology concerned with the outer spheres of the Earth were preoccupied with determination and description of the momentary and local behaviours of their ever changing media and scrutiny for farther connections both in space and in time pointing towards closer contacts with geo-sciences have been therefore neglected.

This is especially valid for the study of the biosphere, a characteristic terrestrial evolutionary form appearing on the junction of the outer spheres (lithosphere, hydrosphere, atmosphere). Palaeontology beat rather a fossil-identifying and describing path for immediate support of the geological dating. The biological approach of the living organism hidden behind the fossil has been restricted to isolated undertakings — even after achievements of world fame (a. o. Hungarian ones e. g. F. NOPCSA, K. LAMBRECHT). Thus it could not reach and maintain a permanent and close contact with biology indispensable for its sound development. Geography destined for surface and human stressed syntheses could not pay vivid attention to the central aims of geology due to its eccentric location among earth sciences shifted towards economic and humanistic sciences and due to its disinterest for far geologic past.

These broad outlines are intended to characterize former disintegration of geo-sciences and to point out its drawbacks for the particular and common advancement of sciences. Main profit of the quarter of a century balance of geo-development is the elimination of barriers preventing approximation and communication of neighbour branches and occupation of interdisciplinary "no man's lands", prosperity of common enterprises. This equipped earth sciences in Hungary like throughout the world with seven-league boots and cosmic wings to live to see never dreamed progress and to reach neighbour planets.

Enumeration of geonomic results should be biased if only scientific achievements and their interactions were considered. In them and behind them we must realize, that not only the scientific reasoning and methods undervent perfection but a great change is to be recorded in the social awareness of scientists on the one side and in the support as well as in the expectations manifested by the society towards the scientist or science itself. Convergence and mutual integration of sciences or branches is a world-wide phenomenon. But in addition cultivation of science tends universally towards team-work, co-operation of widely different branches (specialists) on a high level of programming.

By approaching from this side the inner and outer conditions, social background of the great upswing of geo-sciences, the new motivs of post-liberation scientific activity can be best understood and thus its growing vigour and inexhaustible internal reserves are causally explained.

The great revolutionary sweep of 1848 which yielded prominent achievements on the field of geo-branches cultivated at that time and by which "geonomists" (mineralogists, petrographers, geologists, palaeontologists) acquired in those days high appreciation at home and abroad, lost its drift before outset of the present century. Activity in earth sciences has been curtailed between the two world wars according to narrow (business or personal) interests and particularism got overhand.

1945 marks an extremely sharp limit in history and policy of geo-sciences: the geonomist formerly surrounded by restrictions and fences, hindered in getting scientific oversight or even getting acces to the locality to be examined, found himself at once in the possibility to investigate the Hungarian earth in any scale and got in possession of never dreamed research means. It should not be ascertained that since that moment things had turned ideally and research in earth sciences had start to operate with top efficiency.

Today, in the perspective of a quarter of a century, his attitude seems to resemble to that of Poor John of the fairy-tails uncapable of managing his fortune fallen in his hands. Until then scientific work has been tolerated in all categories ("civil servant", "company expert", "fanatic of his hobby") but with reservations (authority, mining claim, business secrecy) lacking hope or perhaps desire of scientific or regional entirety. The first answer upon disappearance of obstacles was greediness, impatience to overtake at once all the arrears of the past. This brought about not only the frittering of extremely low efficiency but the panic of "we are extremely few", too, and this gave way on the lines of training and reinforcement to undeliberated emergency measures, harmful effects of which could not get over as yet.

More than 10 years were needed to establish and settle new ranges and norms of research work on the field of geo-sciences. In the meanwhile geonomist had to realize that widening of competency and efficiency is unevitably

coupled with widening of responsibility and the specialist has to be aware, he were host of the plot he is working on, on account of his own scientific branch. Necessarily consciousness ought to be awaken of the demanded equivalent of the generously subventioned investigations: complete and up-to-date answer to all the raised questions, bringing economic (practical) aspects into relief, and accomplished within time-limits. Understanding of this required abandoning of former individualistic principles of scientific work, getting mastery of reasonable planning, self-adjustment to fit into scheduled teamwork. On the field of work organization first of all credit towards the scientist had to be established, right dimensioning of research tasks, further weighting and concentration proportional to capacity and possibilities had to become current.

A quarter of a century assures nearly historical perspectives for adjusting objective balance. Delusion, stating that all had gone without roundabouts could not serve any purpose. We drew a lesson from our mistakes and we hope, rising generation shall learn even better. Successes emerge, however, in such an abundance in many shades and levels that it should be hardly motivated to grieve, why all this could not be reached more straight, steadily, and efficiently.

Enumeration of quantitative data about research workers, centres, tackled missions, publications etc. — though testify a leap of an order of magnitude — seems to be out place here. The qualitative change in the mind of scientists in their labour zeal, targets and what immediately follows, in their achievements, is even greater.

Scientific entertainment with purpose in itself has became outworn long ago, but even research work conducted by compromises (research where and how it is tolerated) grew out of fashion. Geonomists conscious (by training or by retraining) of the fact that they were responsible for optimum utilization of the country's natural resources, are henceforth with this in mind testing its material, tracing its past, piercing its depths, sounding its outer atmosphere, examining its superficial morphology. And what is more, they want to know and do know from each other's results. The cross-references corroborate and verify achievements on each side and geonomists conquer through joint enterprises formerly inaccessible fields of investigation, such as secular reversals of the magnetic pole, convective currents in the mantle, recurrences in palaeoclimatology or even environmental background of the leaps of biological evolution.

Not even a general survey of the results by topics can be achieved here. Outstanding "global" advancements will be only flashed according spheres of our planet.

1. The thirties' picture on the 12,740 km diameter inner parts of the Earth seems today extremely primitive, schematic and misleading. The apparently "modern" approach, 25 years ago, based on a coupled interpretation of seismic observations and furnace experience, was actually an erroneous association. We owe to the well organized co-operation of geo-sciences the present profound orientation in the anatomy of our globe. Changes following from "life" processes of Tellus are elucidated by thousands of co-ordinated measurements and model experiments. In the series of world-wide joint geologist-geophysicist enterprises included in the Upper Mantle Project, covering a much broader field than indicated by its name, Hungarian scientists effectuated valuable contributions.

In the elaboration of the theory explaining the indirect control of the core on the shaping and epidermal changes of the Earth, Hungarian scientists have prominent role, just as like in the core-centred explication of the reversals of the Earth's magnetic field. Fifteen years of highly developed seismic deep-sounding, yielding information on the total thickness and "worm's eye" topography of the crust, supplied a coherent picture on the Hungarian part of the crust. This best known section of the European crust famous of its admirable "median mass" evolution documented by a dense network of seismic profiles, solved the problems of specific Hungarian geologic configurations in their "roots".

World rank of Hungarian geophysics has been recognized as early as in the first decade of this century due to achievements of R. Eötvös, while contributions of our geochemistry pulled foreward to leading level but in the last decades. Hungarian geochemical investigation has been focused on the behaviour of volatile compounds. The study of volatile-transfers in function of geologic evolution and fundamental changes following from "life" phenomena of mantle and crust, eliminated contradictions concerning relations of oceanic and continental crust and moreover furnished a link for interpretation of the extraordinary mobility and at the same time horrible strains of the Earth's interior.

2. The lines of force of the activity of geo-sciences concentrate undoubtedly on and near the surface of the Earth (down to depths accessible by mining). This is naturally the sphere itself carrying problems of our everyday life, for which geonomic information reaches its maximum, too, both in quantity and concentration, and which get transformed partially to the "bread of practical life" — sometimes even without retardation.

Indications by measuring of physical parameters — serving as geophysical "feelers" replacing often actual access — gets important role even in this sphere, but specific geonomic material testing and process survey, based in immediate, bodily contact with the Earth's matter, plays leading role. Main principles and trends of these examinations got established as early as the last decades of the past century. Evolutional leap occured in the last quarter of century by conquest of new fields by introduction of new methods (nuclear physics, thermic, X-ray and infrared spectroscopy etc.), by extreme definement of "classic" methods, by exponential increase of measurement (observational) data and last but not least, by the multilateral complex evaluation of findings through geonomic co-operation.

It is definitely hopeless to list, or what is more, to estimate even the top-achievements by basic sciences, branches and "hybrid" disciplines grown in the last decades.

More and better information from Hungarian soil is appreciated not only by its volume but rather by its harmonic fitting and constructional stability. It is just the systematical co-ordination of geonomic research work of different trends and levels for sake of realization of combined undertakings, which eliminated old controversies between "theoretical" and "practical" lines by joining them in a chain of basic, developing and exploitation-controlling researches of a higher unit.

The good "transmission" increased efficiency not only between scientists engaged with basic principles on the one side, and their practical application on the other, but reacted favourably both for the "pure" and "applied"

researchers. Seeing in one ensemble gave equally useful impulses for solving the most abstract questions and for widening horizon of specialists employed in praxis, thus multiplying efficiency of their activity.

It is generally agreed that Hungarian geo-sciences responded with integration of theoretical and practical enterprises, "steeled" in struggling common team-works, most clearly and efficiently to the expectations of the society. The results: theoretical achievements and discoveries important for the whole science acknowledged by international enthusiasm on the one side, and significant progress in the utilization of our mineral raw material and energy sources. The scientific "output" itself demonstrates that the solution of any apparently remote question how tightly and on how many threads is tied to measures taken or to be taken for satisfaction of the daily life's material and energy needs — if seen in its entire geonomic spectrum.

Common efforts of earth sciences succeeded in confuting even the long engraved thesis of general knowledge "Hungary is poor in mineral resources, its reserves are next to exhaustion". On the opposite, the new fashion prospects succeeded in multiplying since the liberation our reserves in "classic" raw materials, widened it by adjoining new ones through checking utility of formerly useless materials insofar, that the value of raw materials and energy exploited from domestic soil exceeds the one secured by import. Elaboration of the scheme of most adequate utilization of the discovered raw material resources and energy bases is a not enough praised merit of our double-faced geography of improved policy.

3. Survey of the outer spheres of the Earth rising to about 60.000 kms above the level of our life (tropo-, strato-, iono-, magnetospheres) and detection of their immediate influence on our living conditions made an enormous progress in the last 25 years. Observation and measurement of artificial moons, further extended radiation soundings made the higher levels of the atmosphere accessible for the Hungarian meteorological research, too. Thus competence of our meteorology has been conspicuously enlarged both in height and in profundity. International appreciation of Hungarian atmospheric researches increased parallel with its closer contact with the solid Earth.

Influences arriving from the Sun and from the interior of the Earth induce periodically returning effects in the outermost spheres of the Earth consisting of the thinnest and most readily agitated media. Their most sensible records (without retardation) are useful for deciphering effects of the same influences on the solid Earth. The yearly Rheological Conferences of the Hungarian Academy of Sciences (organized by the Section of Earth and Mining Sciences) collating respective informations of all interested branches, resulted in mutual integration between "solid" and "drifting" disciplines of geonomy, important on international level.

4. After having summarized geonomic results by their distribution in and on the globe (in space), we owe some remarks on data concerned with the fourth dimension, the time axis, especially important in geology. Exact dating of a several billion years past is not so important in any branch of natural sciences, than in geonomy as a whole.

Recording of geologic time grew out only in the third decade of present century its former stage getting information but by tracing succession, space and time limits of fossilized remnants of former living organisms. First steps towards "digitalization" in dating were made possible by discovery of the

"uranium clock", but only a long evolution has allowed to establish the right norms of handling it and decay rations of other radioactive isotopes. The procedure of selecting, processing specimens, execution of measurements, evaluation and adaptation of data acquired its full scientific armour only in our days as a new offshoot of geology, the *geochronology.*

Bulk of the development starting with estimation of time on palaentological base and tending to measure it, express its length with figures checked by geological, geochemical, mineralogical and petrological references, has been accomplished during the now ending quarter of century. Several dozens of high precision time-measurements afforded by the mass spectrometer laboratory of the Nuclear Research Institute of the Hungarian Academy of Sciences and referring to Hungarian soil as well as to other nembers of the Eurasian Mountain Chain, covering more than one billion years, serve as reliable milestones of geological chronology.

Exponential growth of exact time co-ordinates led to a qualitative change in reconstruction of the past of the Earth. While remains of extinct plants and animals help us only in delimiting periods of the last 600.000.000 years, time recording of our "radioactive isotopes clocks" reaches to the earliest dawn of our planet as far as 5.5 billion years. Following the paths of geochemical processes, distributions of stable isotopes etc. "*hologeology*" dealing with the entire history of the Earth, can be reached, a substantial progress compared with earlier "*merogeologic*" recapitulations concerned but with 1/8 of the whole planetary age (SZÁDECZKY-KARDOSS).

The rushing development of geo-sciences in the last 25 years, its grandiose achievements largely increasing economic and social importance of all geonomic branches involved, should not be realized without maximum concentration of forces and without securing reinforcement by all means. Success in training good specialists was a pledge of all accomplishments.

Today, encountering with unmistakable signs of overproduction of technicians in some branches, we have to turn towards rising general knowledge in geo-sciences again. In past decades all forces got concentrated for special training and in the meanwhile earth sciences have been superseded in the curricula of grammar schools and even from that of their teachers. Re-establishing right share of geonomy in general erudition and thus gaining social understanding and support for our researches is the next important — undoubtedly difficult — task.

PROF. DR. GÁBOR PANTÓ
corr. memb. of the Hungarian
Academy of Science
Institute of Geology and Mineralogy
Debrecen 10, Hungary

PROBLEME UND PROGRAMME EINER MODERNEN PETROGRAPHIE

FRANZ ANGEL

I. STELLUNG UND ALLGEMEINE AUFGABE EINER PETROGRAPHIE

Petrographie ist ein Zweig der Petrologie und gehört daher mit dieser zum Kreis der Erdwissenschaften: Mineralogie, Geologie, Geochemie, Geophysik, Geographie, Ozeanographie, Absolutaltersforschung. Ihre zentralen Objekte sind die Gesteine, die sie qualitativ und quantitativ zu beschreiben und systematisch zu ordnen hat. Mit der Erfüllung dieser Aufgabe liefert sie der Petrologie eine Fülle von Erfahrungsdaten und Material als Unterlagen zur Verfolgung petrologischer Zielsetzungen.

Die gesamten Erdwissenschaften haben — besonders nach dem 2. Weltkrieg — einen solchen literarisch belegten Umfang in Methodik und Ergebnissen erreicht, dass der einzelne Fachmann nicht mehr imstande ist, die Detailliteratur der wissenschaftlich tätigen Völker und Staaten auch nur zur Kenntnis zu nehmen, wobei die Vielfalt der Kultursprachen eines der Hemmnisse darstellt. Das lastet auf uns, aber auch noch auf der kommenden Generation. So wünschenswert es auch ist, eine lebende Kultursprache mit universeller Geltung für die Verständigung der Fachleute zur Hand zu haben, wir haben es noch nicht. Das tote Latein kann uns dabei nicht mehr helfen, seine Rolle hat wenigstens im westlichen Kulturbereich das Englische übernommen. Wie sich aber Russen, Chinesen, Araber etz. dazu stellen, ist offen. Persönlich meine ich, dass auch Kunstsprachen, wie etwa Esperanto, keine Lösung der leichteren Verständigung werden bieten können. Es kommt ja noch eine Schwierigkeit dazu, die G. FISCHER [1931] deutlich gemacht hat: „Geologisch" z. B. ist eine weltweit selbständige Sprache, provinziell unterteilt in deutsche, französische, englische etz. etz. „Mundarten", überdies aber noch in persönliche Idiome, und es bringt der Fachwissenschaft Vorteile, wenn sich diese Mundarten und Idiome sprachlich und begrifflich ergänzen und befruchten; sinngemäss gilt das nicht nur für die Geologie sondern auch die andern Erdwissenschaften und andere Wissenschaften.

Einen Weg zur Verminderung solcher sprachlichen Schwierigkeiten sehe ich in einer Förderung der Entwicklung der Kulturkontakte dadurch, dass aus fremden Fachsprachen namentlich neugeprägte Fachausdrücke als Fremdworte in die eigene Sprache übernommen werden, und zwar exakt in der originalen Bedeutung. Wenn sich alle Völker entschliessen, diesem Gedanken Raum zu

lassen, dann wird bald eine Verständigung auf internationalen Kongressen möglich sein, und dazu auch eine Erleichterung im Verarbeiten fremdsprachlicher Fachliteratur eintreten.

Sachlich haben zwei Großerfolge der Forschung ein Überdenken von Grundlagen der Erdwissenschaften erfordert: *1.* Die Fortschritte in der Gliederung des Erdballes. *2.* Die Erfolge der Mondforschung.

II. GESTEINSBEGRIFFE

Neben der Petrologie haben namentlich noch zwei andere Erdwissenschaften Interesse an Definitionen des Objekts *„Gestein"*, nämlich die Mineralogie und die Geologie.

Für die Petrologie ist „Gestein" ein grundlegender und zentraler Begriff; die Petrographie muss davon ausgehend entwickelt werden.

Die Mineralogie hat einen anderen zentralen Begriff und ein anderes zentrales Objekt: das Mineral. Für die Mineralogie ist das Gestein eine Mineralparagenese bestimmten Charakters, neben andersartigen Paragenesen, die nicht Gesteine sind, wie z. B. die Mineralparagenesen von Erz- und Mineralgängen.

Für die Geologie ist eine Gesteinsmasse ein geologischer Körper, und die besonderen Gesteinsaspekte, die den Geologen angehen, werden in einem Teilfachbereich bearbeitet, der *Lithologie* heisst; diese systemisiert Gesteine als Lithofazies. Lithologie ist eine Gesteinslehre, gesehen mit den Augen des Geologen.

Daraus folgt, das eine Definition des Gesteinsbegriffes nicht für alle drei genannten Erdwissenschaften die gleiche sein kann. Die alte Geologie überdeckte alle drei Erdwissenschaften und spielt dies örtlich in der akademischen Organisation noch heute. Daher hat sich auch bis heute eine geologisch zugeschnittene Gesteinsdefinition gehalten, die heute unzureichend und verbesserungsbedürftig geworden ist. Zu dieser faktischen Lage seien folgende Illustrationen vorgezeigt:

In allen bisherigen Definitionen des Begriffes „Gestein", die man in Lehrbüchern und ähnlichen Werken der Mineralogie, Petrologie (Petrographie) und Geologie liest, spielt die Aussage eine Rolle, Gesteine müssten wesentliche Anteile der Erdkruste sein; ROSENBUSCH [1901] verlangt, sie müssten geologisch selbständige Krustenteile sein; BERG [1912]: Sie seien anorganische Körper wesentlich beteiligt am Bau der Erdkruste; WEINSCHENK [1907]: Sie seien geologisch selbständige Körper und damit wesentliche Krustenbestandteile; WELLS [1948]: Ein Gestein ist ein Aggregat mineralischer Teilchen, das einen Teil der Erdkruste bildet; SCHARIZER [1912]: Alle Massen, die wesentlichen Anteil am Aufbau der festen Erdkruste nehmen, heissen kurzweg Gesteine; RAMDOHR-KLOCKMANN [1942]: Gesteine sind als Mineralgemenge erkennbare Bestandteile der Erdkruste; oder RAMDOHR—BRUHNS [1939], selbständige Krustenteile; HIMMELBAUER [1924]: Sie sind solche Minerallagerstätten, die (unter den Lagerstätten, Bemerkung ANGEL) mengemässig vorherrschen und damit wesentlich sind im Bau der festen Erddrinde; in gleicher Richtung liegen die Äusserungen von F. BECKE [1921], J. STINY [1929], H. LEITMEIER [1950]. FISCHER [1933]: Gesteine sind wesentliche Bauelemente der festen Erdkruste, feste statistisch homogene

Körper von beträchtlicher, aber nicht genau genormter Größe, die am Aufbau unserer Erdkruste teilhaben.

Diese Definitionen, die aus der deutschsprachigen, gängigen Literatur aus der Feder von Mineralogen, Petrographen und Geologen ausgewählt sind, weil sie mir geläufig und wohl auch Fachleuten in aller Welt bekannt sind, enthalten keine quantitativen Bestimmungen zur Angabe „wesentlich", aber immer sind g r o s s e Massen gemeint.

Von der Forderung „wesentlich" ist ROSENBUSCH schon 1901 abgerückt; Gesteine müßten bloss „geologisch selbständige Krustenteile sein", also einfach „geologische Körper", wie man heute sagt, der Ausdehnung nach unbestimmt. Das bekräftigt er durch ein Beispiel: ein Lamprophyrgang von nur 2 cm Mächtigkeit sei trotz kleiner Masse bereits ein Gestein, wie auch andere „Ganggesteine".

An Hand dieser wenigen Fälle wollte ich zeigen, dass über den Begriff „Gestein" weder eine einheitliche, noch eine allgemein geltende Meinung besteht.

ROSENBUSCH [1901] verlangte in eingehenderer Darstellung für die Zuerkennung des Prädikates „Gestein" vom Objekt die Erfüllung folgender Bedingungen: A) Es muss sich um einen geologisch selbständigen K r u s t e n t e i l von ± konstanter chemischer und mineralischer Zusammensetzung handeln, welcher als M i n e r a l a g g r e g a t in Erscheinung tritt. B) Erfüllung folgender 4 Spezialbedingungen: *1)* Natürliche Abgrenzbarkeit gegen die Umwelt, also Erkennbarkeit als „geologischer Körper". *2)* Ein besonderer, geologischer Erzeugungsakt muss erkennbar sein. *3)* Keine stoffliche Ableitbarkeit aus umgebenden Massen. *4)* Das Objekt muss mit dem Erzeugungsakt abhängig verbunden sein.

RAMDOHR wandte gegen die „Ganggesteine" ROSENBUSCH ein, dass sie die obige Forderung *3)* nicht erfüllen, denn sie (Aplite, Pegmatite, Lamprophyre) seien Produkte aus gewissen Erstarrungsperioden anderer Gesteinsmassen, von welchen sie sich stofflich ableiten, es sei bloß ü b l i c h, sie als Gesteine anzusprechen. Sie erfüllen übrigens die ROSENBUSCH-Forderungen *1), 2)* und *4),* und so wird *3)* wohl nicht gerade auf die Ganggesteine gemünzt sein. Sie stehen heute unangefochten unter den Gesteine gemünzt sein. Sie stehen heute unangefochten unter den Gesteinen (P. NIGGLI, RONNER, STRECKEISEN, TRÖGER u. a.).

Es fällt aber auf, dass unter den ROSENBUSCH'schen Gesteinskriterien *petrographische fehlen.*

WELLS (1. c.) hat sich auch davon freigemacht, Gesteine müßten w e s e n t l i c h e Anteile der Erdkruste sein, sie müssen nur „einen Teil" derselben bilden.

Der Geologe BEURLEN [1939] versucht einen anderen Weg zur Gesteinsdefinition: „Gesteine sind Mineralgesellschaften, die sich aus solchen Mineralien bilden, deren Bestände in chemischen Elementen sich aus bloß 8 Elementsorten konstituieren: O, Si, Al, Fe, Mg, Ca, Na, K". Alle andersartig zusammengesetzten gehörten nicht zu den gesteinsbildenden Mineralien. Hier wird also die Geochemie zu Rate gezogen und deren Daten, auf CLARKE [1924] zurückgehend, verwendet. Da ist ein wichtiger und wertvoller Fingerzeig für das Wesen von Gesteinen in sehr vereinfachter Form vorgetragen; für den Petrographen ist diese Form z u einfach, wie weiter unten noch erörtert wird. Vom geochemischen Kriterium ausgehend, lässt sich ein sehr schwieriges Problem lösen, nämlich die Abgrenzung von Gesteinen gegen Mineral- und Erzgänge.

Aus den vorstehenden Ausführungen ist zu entnehmen, dass eine Bedingung, Gesteine müßten „wesentliche" Teile der Erdkruste sein, nicht notwendigerweise erfüllt sein muss. Sie müßten aber immerhin *Teile der Erdkruste* sein; damit stösst man auf ein anderes Problem. Nur vereinzelt begegnet man dafür anderen Ausdrücken, so bei SCHNEIDERHÖHN (1. c.): feste Erdrinde. Oder man spricht von einer Silikatschale. Bei BORCHERT & TRÖGER [1950] findet man folgende Ausdrücke zu diesem Gegenstand: Erdkruste, normale Erdkruste (mit etwa 23 km Tiefgang), Silikathülle oder Silikatschale, Olivinscheidewand in 60 km Teufe, und Lithosphäre. Ein Modell der eben genannten Verfasser gliedert die irdische Silikathülle bis 110 km Teufe vermittels dreier geophysikalisch ermittelten Diskontinuitäten: Conrad-Diskontinuität (20 km Teufe)-Moho =Mohorovičič-Diskontinuität (40 km Teufe)-Mintrop-Diskontinuität (60 km Teufe), was 3 petrographisch definierbare, dazwischen liegende Zonen ergibt, nämlich zuoberst Sedimente, Phyllite, Glimmerschiefer, Granatgneis und darin Granite; unterhalb davon Diorite, Gabbros, Olivingabbros, und zutiefst schliesslich Pyroxenite, Lherzolite, Dunit. Die Moho wird an die Grenze Olivingabbro /Pyroxenit verlegt. Bis zur Mintrop-Teufe wird das Material als fest erachtet, daher Silikathülle, „feste Erdkruste", am besten: Lithosphäre.

Der feste Zustand reicht indes noch tiefer, bis etwa 80 km Teufe; hier liegt der Griquait, ein Tiefenmagmatit in Eklogitfazies [BECK, 1907], vgl. auch BORCHERT-TRÖGER [1950], SMULIKOWSKI [1968] am Prager Kongress. Der Griquaitbereich hiess früher einmal bereits Eklogitschale. Darunter liegt zwischen 80 und 100 km die „Gutenberg-Zone", hypothetisch eine Übergangszone Griquait/Basaltmagma, also nicht mehr fest, nicht mehr Lithosphäre. In Teufen über 100 km herrscht eine alkalibasaltische Schmelze. Dies Modell ist nun über 20 Jahre alt, hat aber bisher nicht jene Beachtung gefunden, die es verdiente.

Am Prager Kongress 1968 kam im Abschnitt *„Upper Mantle"* zum Ausdruck, dass es sich durchgesetzt hatte, nur die Teufen bis zur Moho als Erdkruste anzusprechen, gleichgültig, wie diese Diskontinuität lokal verläuft, die unterhalb anschliessende Teufe aber als Mantel. In der so gemeinten Erdkruste kann man — dem BORCHERT-TRÖGER'schen Modell entsprechend — eine Ober- und Unterkruste abgrenzen; auch im Mantel kann man so differenzieren! Der „obere Mantel" ist uns im Wissen nun schon recht nahe gerückt, und die Aussage, er biete Gesteine, hat bedeutende Sicherheit bekommen [BELOUSSOW, SOBOLEW, DEICHA, JACKSON, HSU & SCHLANGER, AFANASEJEV, SMULIKOWSKI, ROST, KANASEWICH & COLWES, 1968].

Eine Gesteinsdefinition, die verlangt, Gesteine müßten Gebilde der Erdkruste sein, is nunmehr korrekturbedürftig; besser wäre die Aussage, die Gesteine seien Bauglieder von Kruste und oberen Mantel; und damit stimmts auch nur für *irdische* Gesteine! Unzutreffend wäre auch eine Aussage, die Gesteine seien Bauglieder der irdischen Silikatschale, denn diese umfasst auch Kristallbreie, also flüssig und fest gemengt, und magmatisch-flüssige Massen. Wenn man diesen Schwierigkeiten bei der Gesteinsdefinition ausweichen will, so darf man den Passus Erdkruste überhaupt nicht in die Definition einbauen wollen.

Überdies verfügen wir nun über Proben vom Mond, die nach den ersten gründlichen Untersuchungen in Chemismus, Mineralbeständen und Strukturen solche starke Analogien zu irdischen Gesteinen erkennen liesen, dass man sie

ebenfalls als Gesteine anerkennen muss; es gibt also nachweislich auch ausserirdische Gesteine. In den Gesteinsdefinitionen muss daher die Forderung, Gesteine müßten unbedingt i r d i s c h e Bildungen sein, fortfallen, denn sie ist nun anachronistisch.

Was bleibt also von den alten Gesteinsdefinitionen erhalten? Wenn man einschränkend zunächst nur irdische Bildungen im Auge hat, wie etwa ein G e o l o g e, so bleibt, dass irdische Gesteine geologische Körper sind, erfüllt von Aggregaten mineralischer Teilchen; lassen sich in engster Analogie damit Objekte und Beziehungen auf andern Himmelskörpern nachweisen, so ist die Beschäftigung damit nicht mehr Geologie, sondern etwa **Parageologie** zu nennen, um auszudrücken, dass es sich um wissenschaftliche Forschungen analog zur Geologie, mit deren Methoden und passend analogen Fragestellung, aber an ausserirdischen Objekten handelt. Von anderer Seite lauteten Benennungsvorschläge auf „Astrogeologie" [MILTON, 1969], aber das wäre meiner Meinung nach eine widersprüchliche Wortprägung; „extraterrestrial geology" ist vielleicht entsprechender; „space geology" ist ebenfalls unlogisch, genau so auch „planetary geoscience". Zu erwägen wären u. a. S e l e n o l o g i e für den Mond, wie z. B. auch S e l e n o c h e m i s t r y [INGERSON, 1970] als Entsprechung zur Geochemistry. Da der menschliche Ausgangspunkt die irdischen Verhältnisse sind und bleiben werden, und alle Forschungsergebnisse an ausserirdischen Objekten stets mit irdischen in Beziehung gesetzt werden, erscheint mir der Begriff und Ausdruck Parageologie am besten zu entsprechen.

Es ist wichtig, jene Ausdrücke kritisch zu besehen, welche in Gesteinsdefinitionen für die Verbände der mineralischen Teilchen benutzt wurden und werden. ROSENBUSCH, WELLS und WEINSCHENK sagen dazu „Mineralaggregate", RAMDOHR—KLOCKMANN: „Mineralgemenge"; SCHNEIDERHÖHN: „Minerallagerstätten"; HIMMELBAUER: Vereinigungen von Mineralien; BERG: Massenhafte Anhäufungen von Mineralien; RAMDOHR—BRUHNS: Anhäufungen von Mineralkörnern; BEURLEN: Mineralgesellschaften.

In den meisten Definitionen kommt das Wort „Korn" gar nicht vor, ebensowenig das Wort „Gefüge". RAMDOHR—BRUHNS machen mit dem Korn eine treffende Ausnahme. Die Ausdrücke Anhäufungen, Gemenge, Mineralgesellschaften, Mineralaggregate, Vereinigungen von Mineralien gehen an zwei fundamentalen Erscheinungen vorbei, von welchen Gesteine beherrscht werden: am Wesen des mineralischen Korns und am Gefüge. In dieser Beziehung hat B. SANDER einen Zugang zum Wesen der Gesteine geöffnet und in Dezenien von Jahren weiterentwickelt (1911 bis auf heute!).

Eine petrographische Definition für „Gesteine", die der neuen Lage gerecht wird, könnte wie folgt aussehen:

Gesteine sind Gefüge mineralischer Körner, die aus einem kosmochemisch und kristallochemisch kontrolliertem Soma entwickelt werden.

Eine solche Fassung enthält keine Einschränkungen auf terrestrische Verhältnisse, nichts über Erdkruste und Lithosphäre, auch keine Einschränkungen durch Forderungen gewisser Massen- oder Volumsgrössen, oder spezifisch geologischen und/oder mineralogischen Elemente, sondern bloss die exakte Darstellung dreier Parameter petrographisch-petrologischer Natur: Mineralkorn, Gefüge, Soma.

Es gibt freilich auch noch andersartige mineralische Korngefüge, z. B. Kristallrasen, Mineralgänge, Erzgänge. Es wird noch geklärt werden, weshalb sie nicht Gesteine sind und nicht Objekt der Petrographie.

Der Präzisierung der Begriffe mineralische Korn, Gefüge, und Soma dienen die anschliessenden Erörterungen.

III. DAS MINERALISCHE KORN

Seit ROSENBUSCH, ZIRKEL u. a. benutzt die Petrographie zwecks Fixierung des Verhältnisses der kleineren oder grösseren mineralischen Körperchen zum Gestein als Ganzes etwa folgende Ausdrücke: „Gemengteile"; Gesteine sind aber keine Gemenge sondern Gefüge. Ein Haufen Ziegel mit Sand untermischt, das wäre ein Gemenge, aber eine fachkundig aufgeführte Mauer aus Ziegeln, Sand und Mörtel, das ist ein Gefüge. Die Körner eines Gesteins sind nicht seine „Bestandteile" — wie etwa Zeiger und Zahnräder einer Uhr — sondern Gefügeelemente. Auch die Bezeichnungen „Komponenten" — das passt ebenso wie „Konstituenten" zur Diskussion c h e m i s c h e r Verhältnisse und trifft das Wesen weder von Mineralien noch von Gesteinskörnern. Chemische Verhältnisse und Beziehungen haben in anderen Blickrichtungen aber ihre Plätze in der Petrographie.

Das mineralische Korn ist ein Formelement der Gesteine, es ist in seiner Dimension weder nach unten, noch nach oben beschränkt und braucht auch nicht homogen zu sein, es ist aber immer ein selbständiges Gebilde im Rahmen des Gefüges und von sehr großer Mannigfaltigkeit, wie noch an Beispielen gezeigt wird.

Die Kornsorte

Als K o r n s o r t e wird das K o r n im Zusammenhang mit seinen mineralischen Eigenschaften verstanden. E i n f a c h e K o r n s o r t e ist es dann, wenn es homogenen Bau hat, wie das Mineral, nach welchem es zu benennen ist. Ist der Kornbau inhomogen, so soll eine solche Kornsorte k o m p l e x genannt werden. Dazu nun einige Beispiele.

Die Kornsorte *Calcit* unterscheidet sich vom Mineral Calcit nur dadurch, dass sie Gefügekorn ist. Das Mineral Calcit kann sich auch anders darbieten: als frei entwickelter Kristall, als Individuum eines Kristallrasens, als Sinter oder als „Gangart" in Erzgängen. Wenn der Calcit als Gesteinskorn Gefügeelement ist, hat er unter dem Einfluss der Einspannung in das Gefüge besondere gestaltliche Eigentümlichkeiten und eine Reihe von Eigenschaften, die er als Mineral nicht zu haben braucht.

Die Kornart

Noch in jüngerer Zeit hatte die Petrographie wenig Neigung, sich mit Kalksteinen zu befassen. Solange man sich begnügte, Kalksteine als monomineralisch zu kennzeichnen und nichts sonst, gab man sich meist keine petrographische Mühe damit [Vgl. LEITMEIER, 1950]. Aber schon B. SANDER und sein Schülerkreis tätigten an Kalksteinen, Marmoren und verwandten Ge-

steinen Korn- und Gefügeuntersuchungen, welche auch für den Petrographen eminentes Interesse haben, und R. F. FOLK [1962] erstellte ein noch entwicklungsfähiges, petrographisches System für Kalksteine einschliesslich von Dolomiten, das mit seiner genauen Analyse der Körnungen (Mikrit, Mikrosparit, Sparit usw.) zeigt, wie Petrographie auch bei solchen Gesteinen am Platz ist. Mikrit und Sparit sind Kornarten von Calcit; sie sind „einfach", aber Calcit bildet auch komplexe Kornarten, z. B. Fossilien, oder andere „Überkörner", das sind z. B. Großkörner von Calcit, die selber wieder aus kleineren Calcitkörnern aufgebaut sind. Die Anzahl bekannter Calcit-Kornarten ist bedeutend.

Bemerkungen zu anderen Kornsorten und -Arten

Tiefquarz ist eine verbreitete Kornsorte. So wie beim Calcit, findet man oft in selben Gestein nebeneinander mehrere Kornarten, z. B. in Quarzporphyren den „dihexaedrischen" Einsprenglingsquarz, der als Paramorphose nach Hochquarz eine Kornart darstellt, anderseits den sehr kleinkörnigen, pflasterig umrissenen Quarz der mikrogranitischen Grundmasse, den man Quarzmikrit nennen darf; in kristallinen Schiefern eine weitere Quarz-Kornart, „Zahnquarz" oder „amöboiden" Quarz usw.

Die „*Feldspatgruppe*" im mineralogischen Sinn, liefert der Petrographie eine bedeutende Anzahl von einfachen und komplexen Kornsorten und von Kornarten, und diese sollten in petrographischen Beschreibungen genannt und auseinandergehalten werden, wogegen die für die Mineralogie sinnvollen Bezeichnungen und Begriffe Plagioklas, Alkalifeldspat, oder Feldspat überhaupt in petrographischen Bearbeitungen entbehrlich sind. Der Leser solcher Beschreibungen wird dankbar für den Zeit- und Arbeitsgewinn sein, wenn das Kind ohne Umschweife beim rechten Namen genannt wird.

Aus dem ganzen Feldspatrahmen fällt *Adular* als Gesteinsbildner aus. Als einfache Kornsorten kennt man Orthoklas, Mikroklin, Sanidin, Anorthoklas, sowie die Na-reichen Typen; als komplexe Kornsorten dieser Gruppe die verschiedenen Perthite, für welche Mikro- und Kryptoperthite Kornarten darstellen. Das sind noch relativ einfache Verhältnisse gegenüber den Kornsorten und -arten, die aus der Plagioklasreihe anfallen. Hier darf man Albit, Oligoklas, Andesin, Labradorit, Bytownit und Anorthit als einfache Kornsorten verselbständigen, muss ihnen aber, weil sie sich als Mischkristalle von (x Ab $-$ [100 $-$ x] An) darstellen, je ein konventionelles Mischungsintervall zuordnen.

Auf die petrographische Bedeutung der LAVES-Feinheiten sei an diesem Ort nur hingewiesen, ebenso auch auf die vorzüglich brauchbaren Typisierungen der Perthite bei EXNER [1948, 1950].

Bekannt sind die Kornarten des Albit. In Vulkaniten erscheint er entweder als Einsprengling, u. a. Kristallstöcken, und als winzige, leistenschnittige Kornart in Vulkanitgrundmassen, ein quasi Albit-Mikrit. In bestimmten kristallinen Schiefern tritt er als „Ballenalbit" oder „Albitrundling" in Erscheinung, eine andere albitische Kornart also.

Besondere Kornsorten sind die normal- und die inverszonaren Plagioklase, erstere in Plutoniten, welche echte Kontakthöfe verursachen und in Effusiven, die zweitgenannte mit kaum zu erkennender oder aber inverser Zonung ist eine Kornsorte, die für kristalline Schiefer zuständig ist. Da taucht ein Problem

auf, das jüngst A. GREGNANIN an äthiopischen Gesteinen aufgezeigt hat. Er studierte dort Basalte und Andesite. Die meisten Objekte besassen normale Plagioklaszonung, aber man fand nicht näher erklärte Ausnahmen: Im Basalt vom Pass Emni Negarit hatten Plagioklaseinsprenglinge Labradorkerne, 58% An, und Rinden mit 62% An! (Hochtemperaturoptik). Also Zonung invers. In einem Andesit von ebendort gab es Andesin-Einsprenglingskerne 45% An, Rinde 60% An, dazu fiel auf, dass ungewöhnlicherweise die Grundmasseplagioklase noch basischer waren: 64—67% An! Eine Erklärung dieser Phänomene wurde nicht gegeben.

Besondere Kornsorten sind aber auch die von m i r und HERITSCH sen. so bezeichneten *„gefüllten Plagioklase"*, solche mit „echter" und solche mit „falscher Fülle". Es sind das komplexe Kornsorten, bei welchen Fülle und „Wirtskorn" eine Korneinheit höherer Ordnung bilden. Bloß erwähnt seien als eigene Kornsorten die Saussuritkörner gewisser Gabbroider, ferner die Myrmeckit- und Mikropegmatitkörner, die Kornart Schachbrettalbit und „schachbrettähnlicher Albit" [EXNER, 1948]. Es wäre noch eine stattliche Reihe von Kornsorten und Kornarten im Zusammenhang mit Feldspäten zu nennen.

Sehr reichhaltig an Kornsorten und Kornarten sind auch die Pyroxene und Amphibole, und ihnen nachzugehen hat beträchtliche Bedeutung für die Petrographie, möge indes hierorts nur angedeutet werden.

Interessante Fälle finden wir auch bei den Blattspaltern. Abgesehen davon, dass der Petrograph heute Glimmer, Chlorite und glimmerähnliche Kornsorten wie den immer häufiger gemeldeten Stilpnomelan artenmässig genau bestimmen muss, tauchen hier komplexe Kornsorten auf, die oft genug missdeutet werden. Ich erwähne die Parallelverwachsungen von Biotiten mit Klinochlor bis Prochlorit, von denen man oft lessen kann, der Chlorit wäre ein Unwandlungsprodukt aus dem Biotit. Diese Verwachsungen sind von gröber oder feiner mikroskopischem Ausmaß. Bei Sedimentgesteinen bzw. anchimetamorphen Abkömmlingen davon kennt man nun analoge Blattspalter, die komplexe Kornsorten bedeuten, aber im ultrafeinem bis röntgenoptischen Größenmaß: die sogenannten *„mixed layers"*. Auch sie sind nicht etwa Spezies im Umsetzungszustand, sondern eben gesetzmässige Verwachsungen von Feinblättern mit sehr verwandten Strukturen.

Schliesslich seien noch die Paragenesen Olivin (Forsterit) mit Chrysotil einerseits, mit den Kornsorten und/oder -arten wie Bastit, Lizardit, Serpophit, Villarsit, Bowlingit, Xylotil, Iddingsit [ANGEL, 1964] anderseits erwähnt, weil diese Kornsorten die Serpentinite charakterisieren, die keine kristallinen Schiefer sind, gleichwohl aber umgewandelte Gesteine. Ihre Gegenstücke unter den kristallinen Schiefern sind die Antigoritite, die auch noch Olivine bewahrt haben können, und aus der Kornsorte Antigorit mindestens zwei Kornarten entwickelt haben: Grobantigorit und Feinantigorit. Letzterer ist eine Parallele zum Serizit.

Zum *Serizit* noch ein paar abschliessende Bemerkungen: Was man nach mikroskopischen Befunden, so häufig als Serizit bezeichnet und einfach zum Muskowit rechnet, hat mehrere Aspekte. In den Serizitphylliten und Serizitschiefern der Alpen ist diese helle, glimmerige Kornsorte oftmals faktisch ein Feinmuskowit; in vielen Fällen muss das aber erst durch Röntgenoptik und Mikrosonden-Analyse bestätigt werden. Der Korngrössenbereich ist relativ ausgedehnt, aber u n t e r h a l b dessen, was schon mit Lupe als Muskowitschuppe wahrgenommen werden kann. Die Serizitschüppchen der genannten

Schiefer sind jedenfalls auffallend viel größer, als jene von porphyroidischen Grundmassen, die mikroskopisch nur mit Mühe gestaltlich auflösbar und messbar sind (Serizitmikrite). Der Füllungsserizit der gefüllten Albite bis Oligoklase (Ostalpen) ist gröber, die Individuen sind im Mikroskop erfassbar, aber ob das Feimmuskowite sind, ist nicht mit modernen Mitteln geprüft. Sowohl an solchen feinkörnigen hellen Glimmerkorn-Häufchen, als auch bei den hellen Glimmern von gröberschuppigen Glimmerschiefern hat man aber bereits Erfahrungen [HARDER, 1956; LADURON & MARTIN, 1969]. Darnach steht hier die Kornsortenforschung vor reizvollen Aufgaben. Die Glimmerarten Muskowit, Paragonit und Phengit können sowohl selbständig nebeneinander in einem Gestein vorkommen, als in Form von sehr feinen, parallelen Blattverwachsungen, also wiederum eine Analogie zu den schon erwähnten „mixed layers".

Diese wenigen Hinweise sollen Anregungen sein, sich mit der Erforschung von Kornsorten und -Arten intensiver als bisher im Zusammenhang mit der Petrographie zu beschäftigen. Das Mineral des Mineralogen und mineralische Gefügekörner in Gesteinen sind recht verschiedene Objekte!

IV. DAS SOMA DER GESTEINE

Die stoffliche Unterlage mineralischer Gefüge ist ihr Soma, vgl. Paläosom, Neosom, Akyrosom [SCHEUMANN, 1936, 1961; NIGGLI u. a.]. Man kann dieses Soma geochemisch erfassen und gewinnt anhand eines Element-Häufigkeitsdiagrammes auch recht deutlich den Abstand zwischen Gesteinen und Erzgängen. BEURLEN [1939] meinte mit folgenden 8 Elementen das Soma der Gesteine genügend charakterisieren zu können: O, Si, Al, Fe, Mg, Ca, Na, K; CLARKE hatte jedoch bereits mit Ti, Mn, C, H und P die Liste prägnanter konzipiert. Das Hauptmerkmal solcher kurzer Listen ist, dass sie von Quantitäten allein ausgehen und die Qualitäten ausser Betracht lassen. Das ist angängig für Grundlinien der Geochemie, nicht aber für Petrographie. Beispiel: Apatit hat seine Hauptrolle als Nebengemengteil in so zahlreichen Gesteinstypen, dass man misstrauisch wird, wenn er einmal in Gesteinsbeschreibungen nicht erwähnt wird; und das, obgleich er in so geringen Mengen in Gesteine eintritt, dass er auch einmal übersehen werden könnte. *Nebengemengteil heisst aber nicht nebensächlicher Gemengteil;* in meiner Sicht ist er *Nebenkornsorte,* d. h. quantitativ unbedeutend, qualitativ aber gar nicht wegzudenken, und mit ihm das Element P. Der Fall des Mangans ist ebenfalls bezeichnend; es gibt kaum farbige Kornsorten, wo nicht Mn^{+2} in kleiner, aber doch bezeichnender Weise als Fe^{+2}-Vertreter aufscheint, und er ist qualitativ bedeutsam; obendrein aber macht Mn Hauptkornsorten in Gesteinsarten: als Spessartin, als Piemontit z. B. Mit Ce stellen die Lanthaniden ein Element für Hauptkornsorten, z. B. für den Orthit usw. usw.

Ich ziehe es vor, eine Elementenliste für Gesteinssoma etwa wie folgt zu gestalten:

Si, Ti, Al (Cr, La Be), Fe (Mn), Mg (Li), Ca, Na, Na, K (Ba),	8 (6)
H, O, B, Cl (F), C, S, P,	7 (1)

Um die 175 von mir als „gesteinsbildende Mineralien" geprüften Kornsorten aus Elementen vollständig chemisch aufzubauen, benötigt man 8 metallische Hauptelemente und (6) Ergänzungselemente. Die nächste Zeile zeigt die hierbei nötigen Nichtmetalle mit 7 Hauptelementen und (1) Ergänzungselement. Die in

Klammer verzeichneten Ergänzungselemente greifen nur in Spezialfällen durch, i. a. haben sie bei der Kornsortenbildung Sonderfunktionen. Die Hauptelemente finden im Aufbau der gängigen Hauptkornsorten Verwendung, die Ergänzungselemente im Aufbau z. T. weniger häufiger Kornsorten, oder als Beihilfe im Aufbau häufiger Hauptkornsorten. La steht oben für Lanthaniden, damit auch für Ce. Es mag wohl sein, dass die Liste mit Klammerwerten noch um etwas ergänzt werden sollte, aber das bringt keine einschneidende Umgestaltung des Schemas mit sich.

V. ABGRENZUNG DER GESTEINE GEGEN ERZ- UND MINERALGÄNGE

Eine solche Abgrenzung hat seit je und bis heute Sorgen bereitet, deren Ursache z. T. darin liegt, dass es Erze gibt, die tatsächlich Gesteine sind: Chromeisenstein, Spateisenstein, Titanerz-reiche Gabbros und Norite, etc. Aber da liegen die Schwierigkeiten nicht, sondern bei den Erz- und Mineralgängen. Die Trennung von den Gesteinen beruht auf zwei Gegebenheiten:

1) Der geochemische Substanzbestand ist ja andersartig gegenüber Gesteinen, sowohl nach Qualität als nach Quantität.

2) Der Ablauf der Füllung der Gangräume ist ein andere als jener der Erfüllung der Räume von Gesteinskörpern.

Zum Punkt zwei ein paar moderne Beispiele:

I. *Bleiberg in Kärnten,* nach W. POLESNIG [1969].

Phase I. Vorvererzung mit Erzkalzit I, Blende, Fluorit. Begleiter: Dolomit, Pyrit, Markasit, Bleiglanz, Quarz.
Phase II. Haupt-Bleiglanzvererzung mit Bleiglanz, Schwerspat. Begleiter: Erzkalzit II, Zinkblende, Markasit.
Phase III. Schalenblendevererzung mit Erzkalzit III, Schalenblende, Wurtzit. Begleiter: Markasit, Pyrit, Fluorit.
Phase IV. Blende-Flußspatvererzung mit Bleiglanz, Blende, Fluorit, Kanonenspat (=Erzkalzit IV). Begleiter: Baryt, Markasit.
Phase V. Sulfatmineralisation mit Anhydrit, begleitet von Fluorit, Pyrit, Gips, Cölestin.
Phase VI. Metallfreie Karbonat-Mineralisation mit Dolomit, Jordisit, Erzkalzit V. Begleiter: Asphalt, Palygorskit, Pyrit, Rutil.

II. *Piné im Trento,* nach P. OMENETTO & G. DETOMASO [1970].

I. Tektonische Phase, Spaltenöffnungen. I. Metallisation mitt Chlorit, Kupferkies, Arsenkies.
II. Tektonische Phase, Wiederaufreissen, Klüfte, Gänge. II. Metallisation mit *a)* Pyrit, Bleiglanz I, Blende I, Quarz I. *b)* Kupferkies II, Magnetkies, Antimonit, Pyrit II, Bleiglanz II, Fahlerz, Blende (Marmatit) II, Quarz II.
III. Tektonische Phase. III. Metallisation mit Pyrit III, Quarz III, Kalzit.

Diese Gebilde stammen aus Thermen; Gesteine stammen nicht aus Thermen. Ihre Stoffkombinationen trifft man nicht quantitativ und nicht qualitativ in Gesteinen an. Die Erzgänge werden mittels pulsatorischer „Phasen" übereinander aufgebaut; die Phasen (Kristallisationen) sind weder im Gangraum gleichzeitig stofflich da, noch erfüllen sie die Stoffräume einzeitig. In den Gesteinsräumen aber ist die ganze Stoffmasse für die daraus zu bildenden Ge-

steine zugegen, und eine Phasenfolge, die auch nur einigermaßen mit den obigen vergleichbar wäre, gibt es nicht.

Analog ist es mit den Mineralgängen, z. B. jenen der zentralen Ostalpen, die sich ebenfalls qualitativ (Adular auf den Gängen!) und quantitativ (keine summarischen Gesteinschemismen!) von Gesteinen abheben.

VI. DIE PETROGRAPHISCHEN KLASSEN DER GESTEINS-SYSTEMATIK

Somagenetisch ergeben sich drei Klassen:

I. Magmatosome Gesteine,
II. Lithosome Gesteine,
III. Detritosome Gesteine.

Magmatosom sind alle Gesteine, deren Ausgangslage eine primäre, anatektische oder migmatische Schmelzflussmasse ist, deren Soma qualitativ dem Allgemeinbild des Gesteinssomas von S. 123. entnommen werden kann. In diese Klasse fallen alle Plutonite, samt Ganggesteinen, alle Vulkanite, samt Gläsern und Tuffen, alle Anatexite und Migmatite. Es ist an dieser Stelle notwendig, auf die Leistungen von SZÁDECZKY-KARDOSS [1959] und seiner Schule für die Grundlagen einer Systematik dieser Objekte nachdrücklich hinzuweisen.

Lithosom sind alle Gesteine, die ihr Soma aus älteren Gesteinsmassen beziehen und durch Umwandlungen mit oder ohne Stoffwechsel um- und neugestalten. Hieher gehören die Metamorphite aller Arten. Die Umgestaltung allein und für sich kann mittels der Gefügekunde [SANDER, 1930, 1950] erkannt, analysiert und petrosystematisch behandelt werden. Umwandlungen werden erkannt, analysiert und systemisiert mittels der Fazieslehre. Haltephasen der Fazieslehre sind Gleichgewichte. Aber bei Gesteinen aller Art findet man weniger Gleichgewichtsfälle als Ungleichgewichte. In vielen Fällen entwickelt sich eine Gesteinsgeschichte mit Durchschreitung mehrere Fazies *in continuo;* das sind *keine* Metamorphite. In den Fällen, worauf es aber hier ankommt, ist der Fazieswechsel (Gleichgewichtswechsel) erkennbar unterbrochen, und *das* sind dann *metamorphe Gesteine* [ANGEL, 1924, 1965].

Detritosom sind alle Gesteine, die ihr Soma direkt oder auf Umwegen aus jenen Abfällen beziehen, welche die Lithosphäre durch Einwirkung von Atmosphäre und Hydrosphäre anliefert. Detritus im hier gemeinten Sinn sind nicht allein gröbere und feinere Lockermassen, die am Ort bleiben können, oder durch Wind und Wasser abtransportiert und zu neuen Gefügen geordnet werden, sondern auch Niederschläge von Gelöstem (Salzgesteine), aus Hydro- und Aerosolen und aus Wolken, und dazu Niederschläge aus Gelöstem in Tier- und Pflanzenkörpern. Hieher gehören alle Sedimentgesteine, Crescimente [G. FISCHER, 1933], Schnee, Firn und Eisgesteine.

Bei dieser Art der Einteilung bleibt keine Gesteinsart ausserhalb des Systems.

VII. BEDEUTUNG UND PROBLEMATIK DER KORNGRÖSSEN

Für die Lockergesteine ist eine feingliederige Korngrössensystematik entwickelt worden. Leider ist sie nicht einheitlich und keiner der Vorschläge dazu hat sich durchgesetzt, aber jeder der Vorschläge hat soviel Leistung für sich, dass damit operiert werden muss. Man muss es aber auch aussprechen: Petrographisch ist das nicht.

Für Magmatosome und Lithosome, aber auch für so manche Vertreter der Detritosomen gibt es nichts Ähnliches. Es ist der Petrographie auch nicht gedient damit, wenn man für die drei Klassen je besondere Korngrösseneinteilungen aufstellen würde, und ebensowenig wäre es dienlich, die Korngrössenskala bloß beiläufig zu gestalten, so wie etwa grobkörnig, mittelkörnig, kleinkörnig, von Autor zu Autor und von Gesteinstyp zum andern verschieden bemessen!

Ich rege an, alle Korngrössen, deren man in den drei Klassen habhaft werden kann, in *mm* auszumessen, bei isometrischen Körnern im Durchmesser, bei säuligen mit Säulenlänge und Dicke, bei blättrigen mit Tafeldurchmesser und Dicke, daraus eine umfassende Statistik anzulegen und sodann festzulegen, welche Korngrössen in den einzelnen Klassen absolut und nach Häufigkeit Maxima und Minima aufweisen, und schliesslich die Ergebnisse der Klassen zu vergleichen. Das wird zwar eine mühsame, zeitbrauchende Arbeit, aber sie wird sich im Erfolg für die petrographische Systematik in mehrfacher Beziehung lohnen, *u. a. auch für* die *Kornforschung.*

VIII. BENENNUNGSPROBLEME

Eine Einheitlichkeit in der Benennungsweise fehlt, obgleich es sich um ein und dasselbe Fach Petrographie handelt. Am besten eingeführt ist die Benennung bei den Magmatosomen, obgleich sie auch hier nicht nach einem bestimmten Prinzip gehandhabt wurde und wird. Als reich an einer historischen Entwicklung kann man davon Verschiedenes hinnehmen. E. TRÖGER hat in seinem Kompendium für die Systematik der Eruptivgesteine einen sehr wertvollen Modus eingehalten: Dem Gesteinsnamen wird sein Autor mit Jahreszahl an die Originaldefinition beigefügt. Das erinnert an die schon lange gängige Benennungsweise von Pflanzenspezies durch die Botaniker und von Tierspezies seitens der Zoologen, und ist die durchsichtigste und vorteilhafteste Benennungsweise. Für Lithosome und Detritosome ist eine gleichartige Vorgangsweise wünschenswert, und für eine Fortschritt petrographischer Systematik unumgänglich, muss aber von den Anfängen an neu aufgebaut werden. Ich bin dafür, alteingesessene Speziesbezeichnungen beizubehalten mit Beifügnung des Autors und der Jahreszahl.

Man hat von verschiedenen Seiten her z. B. für Lithosome eine Namengebung versucht, welche im Gesteinstitel einfach alle sogenannten „Hauptgemengteile" nebeneinanderreiht; das soll den Vorteil haben, das „man gleich weiss, woraus ein Gestein besteht"; aber das stimmt ja gar nicht; der Name müsste ausserdem noch Textur und Struktur andeuten, und zudem: bei dem „bestehen" wird einseitig bloß an Mineralspezies gedacht. Entscheidend für eine Gesteinsart sind aber gar nicht diese, sondern die Art der Kornsorten und Kornarten, und gerade d i e s e kommen bei einer solchen, unförmigen Benennungsweise zu kurz. Man geht ja auch in den beiden anderen Klassen gar nicht s o vor, weshalb also gerade nur bei den Lithosomen?

Ich finde, dass diese oben kritisierte Art der Namengebung unzweckmässig ist, da man trotz des langen Titels den man konstruiert, den Leser doch nötigt die ganze textliche Gesteinsbeschreibung zu lesen, also Doppelarbeit auf sich zu nehmen, und überdies kommen solche Bezeichnungsungeheuer im Druck zu teuer — ohne zureichende Begründung.

Die Fälle, wo neue Gesteinsnamen notwendig werden, knüpfen sich an Originalfundpunkte. Es ist dann durch die Ortsbezeichnung im Gesteinsnamen,

Autor und Jahrzahl, eine kürzere und prägnantere Bezeichnung möglich; dazu liegen im Bereich der Lithosomen nur Anfänge vor [ANGEL, 1968]. Wenn man das System ausbaut, wird man es in grösserem Ausmaß und rückwirkend als Prinzip einführen.

Bei den Detritosomen ist eine einheitliche, petrographische Benennungsweise nach diesem Prinzip noch nicht in Angriff genommen.

Eine moderne Petrographie kann sich nicht damit abfinden, dass in jeder Gesteinsklasse andere Prinzipien der Gesteinsbenennungen geübt werden. Das ist ein schweres Hindernis für die Gestaltung einer umfassenden, petrographischen Systematik. Also weg davon!

Damit möchte ich diese programmatischen und einführenden Auslassungen abschliessen. Den Literaturnachweis fasse ich aus Gründen von Raum und Kosten so knapp als nur möglich und bitte meine Fachgenossen um freundliches Verständnis dafür.

SCHLUSSWORT

In acht kurzen Kapiteln wurde über Lage und Problematik einer modernen Petrographie kritisch berichtet, diskutiert und Anregungen zu einer modernen Weiterentwicklung einer systematischen Petrographie vorgelegt. Es wurden erörtert:

I. Heutige Stellung und Aufgaben der Petrographie. *II.* Kritik der überkommenen Gesteinsbegriffe und Neufassung einer Gesteinsdefinition, welche die Ergebnisse der Mondforschung und Erdschalengliederung berücksichtigt. *III.* Diskussion der Begriffe Kornsorte und Kornart; ihre Bedeutung für die Petrographie an Beispielen. *IV.* Diskussion zum Begriff Gesteins-Soma, und neue Elementenliste-Vorlage. *V.* Abgrenzbarkeit der Gesteine gegen Erz- und Mineralgänge, mit zwei modernen Beispielen. *VI.* Begründung der drei petrographischen Gesteinsklassen als Ausgangspunkte petrographischer Systematik. *VII.* Problematik der Korngrößen und Anregung zur Gestaltung eines für alle drei Klassen verwendbaren Korngrössenschemas und -Inventars. *VIII.* Kritische Stellungnahme zur Benennungsweise von Gesteinen und Empfehlungen dazu.

Nach Meinung des Verfassers sind dies Kernfragen der Weiterentwicklung einer künftigen, alle Gesteinsklassen einheitlich behandelnden systematischen Petrographie.

REFERENZEN

ANGEL, F. [1924]: Gesteine der Steiermark. Mitt. Natw. V. Steiermark, B. *60,* 1—302.

ANGEL, F. [1964]: Petrographische Studien an der Ultramafit-Masse von Kraubath Steiermark. Mitt. Blatt Abt. f. Mineralogie, Landesmuseum Joanneum, Graz, H. 2, 1—125.

ANGEL, F., LASKOVIC, F. [1968]: Über einige Gesteine aus der Umgebung der Radentheiner Magnesitlagerstätte auf der Millstätter Alpe Kärnten. Radex—Rundschau, H. 1, 3—18.

BECK, R. [1907]: Untersuchung über einige südafrikanische Diamantlagerstätten. Z. D. Geol. Ges. *59,* 275—307.

BECKE, F., TSCHERMAK, G. [1921]: Lehrbuch d. Mineralogie. *8.* Aufl. Wien.

BERG, A. [1912]: Geologie für Jedermann. 1—261. Thomas—Verlag Leipzig.

BEURLEN, K. [1939]: Erd- und Lebensgeschichte. 1—462. Quelle & Meyer, Leipzig.

BORCHERT, H., TRÖGER, E. [1950]: Zur Gliederung d. Erdkruste nach geophys. u. petrologischen Gesichtspunkten. Gerlands Beitr. z. Geophys. *62,* 101—126.

CLARKE, F. W. [1924]: The Data of Geochemistry. Geol. Survey Bull. 770. USA.

EXNER, CHR. [1948]: Tektonik, Feldspatausbildungen und deren gegenseitge Beziehungen in den östlichen Hohen Tauern. Tschermaks miner. u. petr. Mitt. 3. Folge. B. *1,* H. 3, 197—284. I.Teil einer Folge von 5 Publikationen.

FISCHER, G. [1931]: Über Begriff u. Wortbildung i. d. Geologie. Preuss. Geol. Landesanst. Sitzber., H. 6, 31—38.
FISCHER, G. [1933]: Gedanken zur Gesteinssystematik. Jb. Preuss. Geol. La. B. *34*, 553—584.
FISCHER, G. [1935]: Einheitliche Benennung der Sedimentgesteine. (Mit. H. UDLUFT) Jb. Preuss. Geol. La; B. *56*. 517—538.
FOLK, R. F. [1962]: Spectral Subdivision of Limestone Types. Aus Mem. 1. Classification of Carbonate Rocks. Tulsa, Oklahoma, 62—84.
GEOTIMES (News of the Earth Sciences): Die folgenden Nummern enthalten Aufsätze über Ergebnisse der neuesten Mondforschung: Juli—August 1969, Oktober 1969, Jänner 1970, Februar 1970, April 1970.
GREGNANIN, A. [1969]: Magmatismo precoce etiopico. Mem. Museo Tridentino die Sc. Nat. etc. XXXIII—XXXIV, 1970/71, Vol. XVIII/2. 137—172.
HARDER, H. [1956]:Untersuchungen an Paragoniten und natriumhaltigen Muskowiten. Heidelberger Beitr. Min. Petr. *5*, 227—271.
HIMMELBAUER, A. [1924]: Mineral- und Gesteinskunde. Für Oberklassen d. Mitteilschulen. 1—168. Hölder—Pichler—Tempsky, Wien.
INTERNATIONALER GEOLOGEN CONGRESS, Prag [1968] Proceed. Sct. I. Upper Mantle. Acad. Prag 1968. 1—230. Artikel von BELOUSSOW bis KARAMATA.
LADURON, D., MARTIN, H. [1969]: Coexistence de Paragonite, Muscovite et Phengite dans un micaschiste a Grenat de la zone du Mont-Rose. Annales Soc. Geol. Belgique *92*, Fasc. I. 159—172.
LEITMEIER, H. [1950]: Einführung in die Gesteinskunde. 1—273. Springer, Wien.
NIGGLI, P. [1948]: Gesteins-und Minerallagerstätten I. Allgemeine Lehre von den Gesteinen und Minerallagerstätten. 1—540. Birkhäuser, Basel. (und Anschlusswerke).
OMENETTO, R., DETOMASO, G. [1970]: Le mineralizzazioni filoniane a solfuri misti della zona di Pine (Trento). Economia Trentina, Trento 1970, N. 1—2, 1—21 und Tav. I—III.
POLESNIG, W. [1969]: Studium der Erzgefüge in der Grube Bleiberg—Kreuth. Aus FRIEDRICHS Archiv f. Lagerstättenforschung i. d. Ostalpen, B. *9*, 73—106.
ROSENBUSCH, H. [1901]: Elemente d. Gesteinslehre, *2*. Aufl., 1—565, Stuttgart.
RAMDOHR, P., KLOCKMANN, F. [1942]: Lehrbuch d. Mineralogie, *12*. Aufl., 1—659, Enke, Stuttgart.
RAMDOHR, P., BRUHNS, W. [1939]: Petrographie. Göschen Sammlung B. *173*, 1—113.
SANDER, B. [1930]: Gefügekunde der Gesteine. Springer, Berlin.
SANDER, B. [1948]: Einführung in die Gefügekunde geologischer Körper I. (Allgemeiner Teil) 1—215, Springer, Wien.
SANDER, B. [1950]: Einführung in die Gefügekunde geologischer Körper II. (Die Korngefüge) 1—399, Springer, Wien.
SCHARIZER, R. [1912]: Lehrbuch d. Mineralogie f. d. fünfte Klasse d. Gymnasien, 1—157, Tempsky, Wien.
SCHEUMANN, K. H. [1936]: Zur Nomenklatur migmatischer und verwandter Gesteine. Min. Petr. Mitt. *48*, 297—302; Metatexis und Metablastesis. Min. Petr. Mitt. *48*, 402—412.
SCHNEIDERHÖHN, H. [1955]: Erzlagerstätten. *3*. Aufl. 1—375, Fischer, Stuttgart.
STINI, J. [1929]: Technische Gesteinskunde. *2*. Aufl. 1—550, Springer, Wien.
SZÁDECZKY-KARDOSS, E. [1959]: A genetical system of magmatic rocks. Prelim. Abstr. Geochem. Conf. Hungarian Acad. Sci., Budapest 17—27.
TRÖGER, E. [1935]: Spezielle Petrographie der Eruptivgesteine. 1—360. D. M. G., Berlin.
WELLS, A. K. [1948]: In Chambers Dictionary. Einschlägige Definitionen.
WEINSCHENK, E. [1907]: Petrographisches Vademekum. 1—208. Herder, Freiburg.

PROF. DR. FRANZ ANGEL
Kopernikusg. 27/II.
Graz, Österreich

SOME PROBLEMS IN DETERMINING THE OXIDATION STATE OF SEDIMENTARY ROCKS

Preliminary report

Gy. Grasselly and M. Hetényi

INTRODUCTION

The determination of the oxidation state of sedimentary rocks may largely contribute to a detailed understanding of the conditions of sedimentation and of the nature of diagenetic processes, to the general characterization of sedimentary rocks as well as to the further development and refinement of their classification.

From the related literature many attempts are known concerning characterization of the *"oxidation state"* of sedimentary rocks and determination of *"redox relations"* or *"reducing properties"* of sediments.

The investigations aimed at the characterization of "oxidation state" of sedimentary rocks are connected both methodological and conceptional difficulties. A considerable part of methodological difficulties could be eliminated by introducing precise and accurate methods. As to the difficulties of principle we should like to refer to a remark of the classic work of Zobell [1946] according to which it is more easier to carry out precise measurements then to interpret the meaning of the results obtained.

Considering the foregoing investigations and the results and statements obtained, it seems that this complex of questions requires and — owing to its importance — also merits further studies.

Though the immediate aim of this preliminary report can only be sought in presenting some new aspects of the approach to the problems connected with the oxidation state of sedimentary rocks and in considering the possibilities of interpreting the measurements, it may be expected that the observations and reflections summarized below will contribute to a better understanding of this important and interesting problem.

SOME METHODS OF DETERMINING THE OXIDATION STATE OF SEDIMENTARY ROCKS

To determine the oxidation state of sedimentary rocks on the basis of chemical analysis, Szádeczky-Kardoss [1955] used the iron-oxidation-value $\left(O_{Fe}=\frac{2Fe_2O_3\ \%}{FeO\ \%}\right)$ and, he designed the place of different sedimentary rock

types in his system by using this value and the compound potential. The latter value can be calculated from the ionic potentials of the cations and anions present, taking into account the analytical data of the rock in question.

SZÁDECZKY-KARDOSS's system was successfully applied also by G. CSAJÁGHY [1965] for the geochemical classification of peloids rich in organic matter.

In characterizing the oxidation state of rocks by the iron-oxidation-value or oxidation grade, the meaning of this value is unequivocal. Some troubles may, however, arise in the case of peloids rich in organic matter because greater amounts of organic material, depending on its character, may interfere with the precise determination of the iron (II) concentration, diminishing in this way the reliability of the oxidation grade. The calculation of the average compound potential of the rock investigated may lead to further troubles, since this calculation would involve the total chemical analysis of the rock, though in his work referred to, SZÁDECZKY-KARDOSS gives the average compound potentials for different types of sedimentary rocks.

The oxidation grade used in the above conception for characterizing the oxidation state of rocks turns our attention towards the group of considerations which try to characterize the oxidation state by the oxidation-reduction relationship.

KRUMBEIN and GARRELS [1952] classified the chemical sediments on the basis of the Eh and pH of their enviroment, taking into account the Eh and pH conditions under which the mineral phases of given sediments may be precipitated from their solutions and may be considered as stable, respectively. The classification of mineral facies by SHTCHERBINA [1939] was also based on redox potential values.

It is, however, a different problem to determine, on the one hand, the probable conditions of formation of the main sedimentary rock types and their field of stability in function of Eh and pH, and, on the other hand, to find a way of determining the oxidation state or reducing properties of the rocks themselves. The oxidation state of the rock undeniably reflects in a lesser or greater degree the effects of the oxidation-reduction relationship prevailing during the formation of the sediment as well as the postdepositional changes in Eh and pH of their environment. In our opinion, the very origin of the problems of principle lies in trying to determine and characterize the oxidation-reduction properties of given sedimentary rocks.

BOD and BÁRDOSSY [1959] in their detailed investigations developed a new method of determining the oxidation-reduction relationship of sedimentary rocks. Their method essentially consists in introducing the powdered rock sample in sulphuric acidic potassium dichromate solutions of different concentration (0.001 to 0.1 N) and measuring the changes in potential of the solutions as a function of time. The changes in potential measured at the time t_1 and t_{24} 1 hour and 24 hours after the beginning of the run, respectively allow to draw conclusions concerning the oxidation state of the sample, its resistivity against oxidation, as well as the character of oxidation-reduction processes taking place. The potential changes measured in potassium dichromate solutions of different concentration will be the lower the stronger oxidized the rock is, and therefore, the less its effect in changing the potential of the solution. In the case of more reduced rocks greater changes of the potentials will be observed. If the stability of the rock against oxidizing agents is lower, so that, the oxi-

dation proceeds quickly already in the beginning, potentials measured at the time t_1 and t_{24}, respectively, will show less differences. On the contrary, if the rock is resistive against oxidation, the potential of the solution will change only gradually and consequently greater differences between the potential values measured at the time t_1 and t_{24}, will be found.

A. A. DROZDOVSKAYA [1963] dealing with the method of BOD and BÁRDOSSY, stated that though the method can be easily carried out and gives the possibility to compare different rocks concerning their oxidation state, the interpretation of the data obtained, however, is rather complicated and involves much graphical work.

Essentially, the difficulties mentioned in the introduction are met again, namely it is possible to measure certain values accurately and reproducibly, but the question as to the exact meaning of the values obtained invariably subsists, the more as even the authors referred to emphasized that the potential measured with their method is not equivalent with the "redox potential" of the rock.

It seems obvious that the best approach to the interpretation of the measurements can be found by elucidating the role of the different factors present in the system in producing the potential measured, and by determining the character and the amount of their contribution to the measured potential value, the potential in an aqueous suspension of the powdered rock sample being obviously a resultant of the interaction of all contributing factors.

ZOBELL [1946] in his paper on the redox potential of marine sediments applies the *reducing capacity* for characterizing the reducing properties of the sediments.

By definition, the reducing capacity means the quantity of oxidizing agent necessary to change the potential of the system by 1 Volt, i. e. the reducing capacity may be expressed as

$$\frac{\Delta C}{\Delta E} \left(\frac{\text{Moles}}{\text{Volts}} \right).$$

In marine sediments redox systems with different redox potential within a wide range may be present and, according to their character, they will play different roles in influencing the reducing capacity of the system. Non-consolidated marine sediments, rich in organic matter, generally show higher reducing capacities. The development of the reducing conditions is partly connected with the presence of H_2S, however, in many of the sediments iron(II) may also act as an important reducing factor. Furthermore, the organic matter itself can also have reducing effects.

To determine the reducing capacity e. g. of soils, STURGIS [1936] used diluted solutions of potassium dichromate containing potassium sulphate, and he calculated the reducing capacity by determining iodometrically the decrease of the oxidizing agent in an aliquot taken after a certain time from the supernatant of the soil-suspension.

The method of TRASK and HAMMAR [1935] is similar in principle, except that they used chromic acid to determine the reducing capacity. BOD and BÁRDOSSY's method is based on the same principle, too.

The consumption of the oxidizing agent is determined by the interaction of several factors, so, of the quantity and oxidation state of the organic ma-

terial and the possibility of being oxidized under the experimental conditions; but, of course, the oxidizable inorganic compounds will also play a role.

According to ZoBell, a source of error of the methods mentioned consists in the fact that on the one hand, some reduced organic components in the soil or in the sediment will not be oxidized and, on the other hand, less soluble reducing inorganic compounds will not be affected by the oxidizing agent. Furthermore, in sediments rich in organic matter the use of strong oxidizing agents is not favourable. In our opinion, the difficulties mentioned by ZoBell unfortunately exist in every method known up to this day. The problem could be solved if it were possible to study the character and the extent of the effect of the different factors controlling the redox potential and reducing capacity of the system obtained from the suspension of the sediment separately.

An ideal oxidizing agent for determining the redox capacity of sediments containing organic matter should be one of relatively high Eh but not sufficiently oxidative to destroy the organic matter; it should only affect the reversible ox/red systems but not react with the components of the ox/red system.

ZoBell proposed slightly acidic $FeCl_3$ solution as an oxidizing agent which, though not ideal, yet could be acceptably used for characterizing the reducing capacity of non-consolidated sediments rich in organic matter. He measured the potential in suspension, excluding the effect of atmospheric oxygen, then titrated the suspension with $FeCl_3$ solution, waiting for the equilibrium after the addition of each aliquot, then measured the Eh. He continued the Eh readings till the Eh did not change on addition of further drops of $FeCl_3$ solution. The reducing capacity of the sediment is charaterized by the shape of the titration curve. He was able to show in this way that e. g. the reducing properties of three sediments, characterized by the trend of the curves, were different, though the starting Eh values of the suspensions were the same and the final Eh values at the end of the titrations were also equal.

EXPERIMENTAL

Experimental conditions

The aim of these preliminary investigations was to find an approach to the solution of two problems; namely

a) to attempt to reveal separately the factors controlling jointly in their interactions the course of the potential curve, provisionally outlining the possibilities at least and

b) to elaborate a way of expressing the reducing capacity of sedimentary rocks not only by the shape of the titration curves but possibly by a numerical value derived from the potential curve.

In performing the measurements, 0.05 M $FeCl_3$ solution was used as oxidizing agent, its pH being adjusted to $\sim$ 3 to prevent hydrolysis. In a covered plastic cell 10 grams of rock ground to less than 0.06 mm grain size were suspended in 50 ml distilled water boiled and cooled to room temperature previously. The Pt-electrode, the gas-inlet-tube and the agar-agar — sat. KCl bridge connecting the cell with the saturated calomel reference electrode were introduced through the cover. The measurements were performed in nitrogen atmosphere, under continuous stirring with a vibrating stirrer.

After measuring the initial potential of the suspension, $FeCl_3$ solution was added by 0.5 ml portions. After each dosis, when a relative equilibrium had come about (3 to 7 minutes), the potential was read. The adding of the oxidizing agent was continued till a relatively constant potential was reached, then the potential (in mV) was plotted against the consumption of oxidizing agent (in ml).

In the *run 1* the potential curves of suspensions prepared from original, untreated rock samples were recorded. These curves are shown in *Fig. 1.* The samples were Lower Pannonian sedimentary rocks.

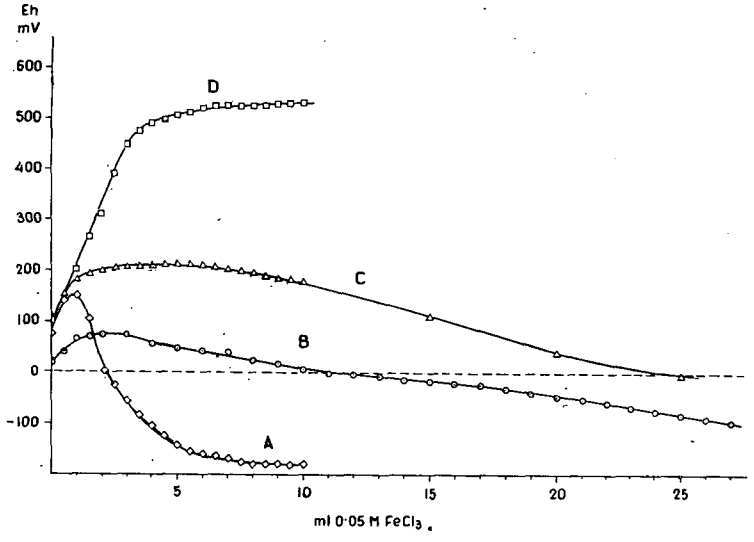


Fig. 1. Redox potential change of suspensions of different sedimentary rock samples in function of the quantity of the $FeCl_3$ solution added to the suspension.

Sample *A* is light gray, fine-grained-sandstone; in thin section very little carbonaceous plant remnants can be observed; the sample contains muscovite, biotite and chlorite.

Sample *B* is also a fine-grained sandstone with marly embeddings, with little carbonaceous plant remnants in some places and parts richer in muscovite and biotite.

Sample *C* can be described as a lime-marl without any characteristic features in thin section. After dissolution of the carbonates, the residue consisted of kaolinite, muscovite, chlorite, goethite and quartz, according to DTA and X-ray investigations.

Sample *D* is a sandy conglomerate; little abraded quartz pebbles and some feldspar was embedded in the coarse sandy fraction; in thin section besides relatively much muscovite, other phyllo-silicates could not be observed.

DTA curves of the mentioned samples are shown in *Fig. 2.* The differences in the carbonate content (magnesian limestone and calcite, respectively) of the

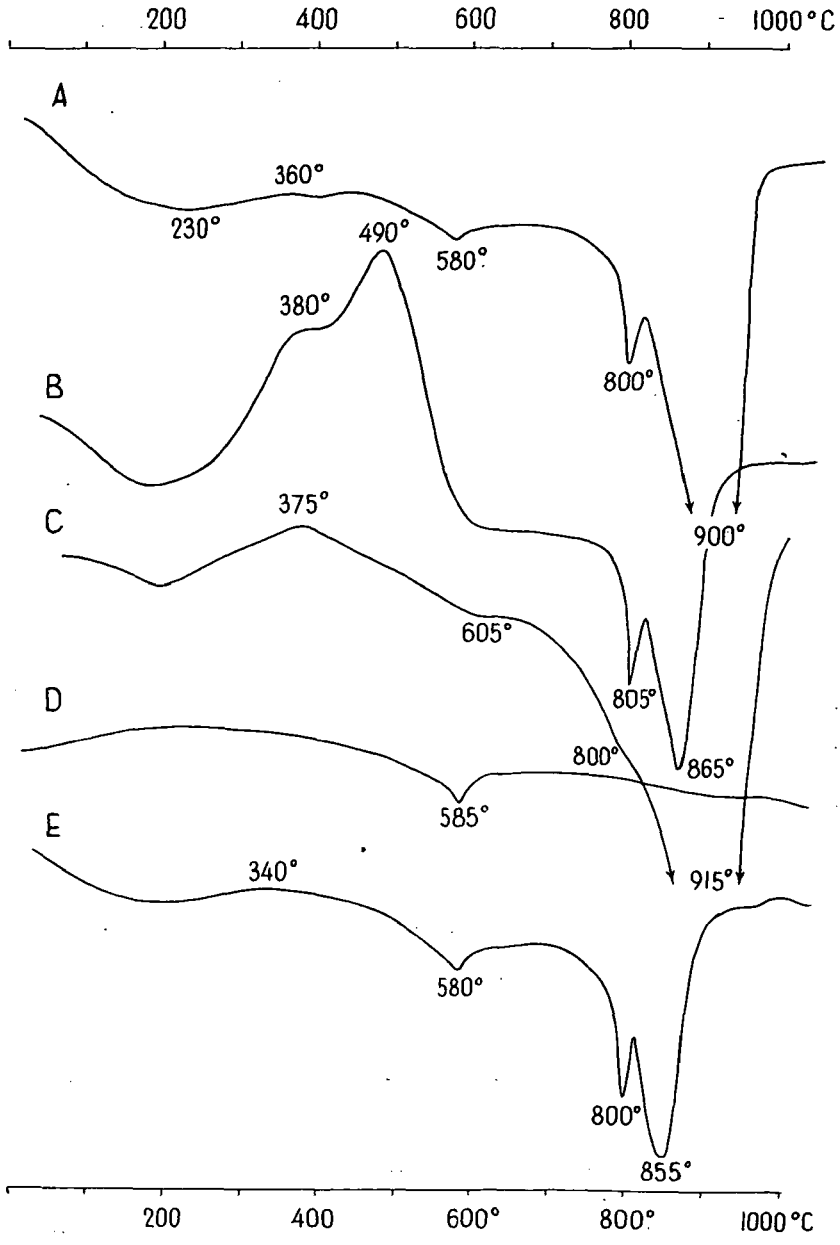


Fig. 2. DTA curves of the samples investigated (description of the samples see in the text).

samples can be well observed in these curves; the double exothermic peak between 415° and 490° C in curve *B* points to the organic matter content of this sample.

It seemed interesting to clear up whether the organic matter content of the samples exerts any influence on the potential curves and, if so, to determine the character of this influence. For this purpose sample *E* containing minimal quantities (0.16 per cent organic C) of organic matter was chosen. Sample *E* was also a fine-grained sandstone, with carbonate cementing material, embedded claystone pebbles, muscovite, subordinate quantities of biotite and sericitized orthoclase. The potential curve of sample *E* is represented by curve *E* in *Fig. 3.*

In the *run 2* three per cent of different kinds of natural organic matter were mixed to the powdered sample *E* and the titration curves of these suspensions, shown in *Fig. 3*, were recorded. The organic matters mixed to the rock *E* were the following:

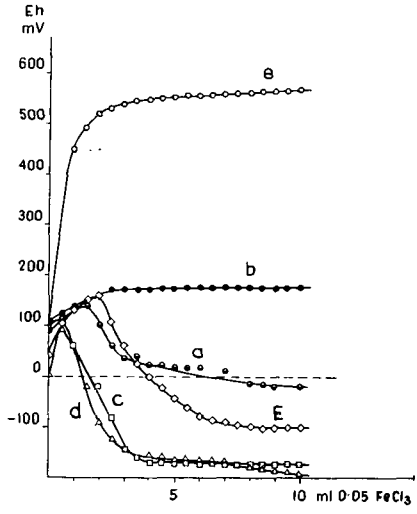


Fig. 3. Effect of different organic materials on the change of the redox potential curve of the same sample.

a) lignite (curve *a* in *Fig. 3*);

b) kerogen extracted from a rock sample rich in organic matter, according to the method described by FORSMAN and HUNT [1958]; it should be noted that this kerogene consisted not only of organic matter insoluble in organic solvents, but also contained little carbonaceous plant remnants and was contaminated by the admixture of some inorganic matter formed during the preparation (curve *b* in *Fig. 3*);

c) petroleum fraction distilled in the temperature range 280° to 300° C (curve *c* in *Fig. 3*);

d) petroleum fraction distilled in the temperature range 300° to 350° C (curve *d* in *Fig. 3*), and finally

e) petroleum fraction remaining in the flask after distillation up to 350° C (curve *e* in *Fig. 3*).

In the *run 3* the potential curves of twenty seven samples of sedimentary rocks, similar in character to those mentioned above, were recorded under the

same conditions. These curves are not shown separately; only the upper and the lower limiting curves of potential curves grouped according to their similar character, as well as the mean potential curves calculated for each group are presented in *Figs. 4, 5* and *6*.

Possible interpretation of the potential curves

Considering carefully the character of the curves in *Figs. 1* and *3*, three different types can be distinguished. In *type I* the potential of the suspension rises with increasing quantities of $FeCl_3$, till, at a certain level, a relative equilibrium is reached. In the curves of *type II*, after an initial slight increase, the potential reaches a maximum, then it decreases again to attain a relative equilibrium at a low potential. The curves of *type III* range between type I and II; after a less pronounced initial maximum the potential decreases and approaches only very slowly an equilibrium.

In first approximation, the increase and decrease or the relative constancy of the potential can be brought into connection with the changes in concentration of the Fe^{3+} introduced in the system, i. e. with the concentration relationship of the ox/red system formed. A decrease of the Fe^{3+} concentration results in a decrease of potential, however, the decrease in Fe^{3+} concentration may occur not only in presence and as a result of reducing organic components but the adsorption of Fe^{3+} on the particles of the suspension, and/or hydrolysis can also lead to the same effect. Yet, should the decrease of the Fe^{3+} concentration and consequently that of the potential be effected by the latter process only, then the potential curve could hardly be considered as characteristic for the reducing property of the rock suspension.

Considering the potential curves shown in *Figs. 1* and *3*, it appears, however, that besides the possibility mentioned above,factors closely connected with the character of the rock play also a determinative role and so, the trend of the potential curve can be brought into connection with the peculiarities of the rock. Thus, the four rock samples of *Fig. 1* gave three different titration curves, and also the potential curve of the rock sample *E* in *Fig. 3* showed changes according to the character of the organic matter added to this sample.

As to the potential curves of *type I*, obtained e. g. with the rock sample *D* as well as with rock sample *E* containing kerogen or the residual petroleum fraction after distillation over 350° C, it seems that in case of curve *D* in *Fig. 1* and curve *e* of *Fig. 3*, on adding $FeCl_3$ the potential attains a relatively higher constant level corresponding to the concentration relationship of the Fe^{3+}/Fe^{2+} system and further addition of $FeCl_3$ causes no further changes. It seems at the first sight, as if in the case of curve *D* in *Fig. 1* and curve *e* in *Fig 3* components reducing the Fe^{3+} and thus diminishing the potential were not present or as if the Fe^{2+} concentration to be found in the sample were to low to cause a significant decrease in potential.

Curve *b* in *Fig. 3* is of similar character, however, the potential in its relatively constant interval is about 340 mV lower measured against saturated calomel-electrode. A possible interpretation of the difference between curves *b* and *e* in *Fig. 3* can be sought in the fact that in case of curve *e*, the 3% petroleum distillation residue added to the sample *E* and containing 87.04% C and 11.81% H proved to be free of sulphur, whereas in case of curve *b* the 3%

kerogen added to the same rock sample contained 6.22% S, and the presence of reducing sulphur compounds may diminish the Fe^{3+} concentration and thus the potential.

The relatively constant interval of curves *c* and *d* in *Fig. 3* is even lower than the potential of the untreated suspension of the sample *E*. In the curves *c* and *d* the potential, after a slight initial rise, becomes constant at about −170 mV. The two curves of very similar character were measured in the suspension of the powdered rock which contained 3% of the petroleum fraction distilled from 280° to 300° C and from 300° to 350° C, respectively. The average composition of these two fractions is 84.80% C, 13.51% H and 1.58% N. As the original rock sample *E* was the same in each case and in

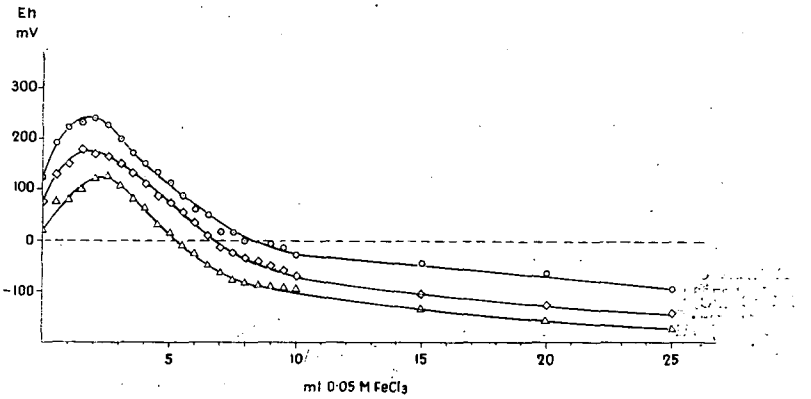


Fig. 4. Limiting and mean redox potential curves, respectively, characteristic of group I of the rock samples investigated.

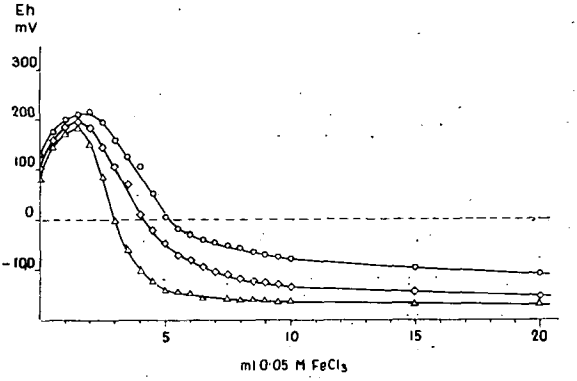


Fig. 5. Limiting and mean redox potential curves, respectively, characteristic of group II of the rock samples investigated.

presence of the components mentioned the potential was depressed with respect to that of the pure rock sample, it is obvious that the more pronounced decrease of the potential is to be ascribed to the reducing effect of the hydrocarbons added.

Carrying out the measurements with suspensions of numerous sedimentary rock samples mostly fine-grained sandstones with carbonate cementing material potential curves similar to curve *A* in *Fig. 1* and curve *E* in *Fig. 3* were obtained, as shown in *Figs. 4* and *5*.

In cases if the potential decrease cannot be attributed to reducing compounds or explained by the presence of reducing organic components, the question will arise, by what factor or what process the decrease in potential may be accounted for.

As briefly mentioned above, one of the possible answers may be found in making responsible the clay fraction or the fine-grained suspension itself for the decrease of the Fe^{3+} concentration, the Fe^{3+} being bound on the surface of the fine particles and/or the Fe(III)-hydroxide precipitated due to hydrolysis adsorbed on the surface of the fine particles.

This supposition seems to be supported by the fact that titration of the suspension of rock *E* with $FeCl_3$ solution of higher (0.25 M) concentration gave a curve which was initially similar to curve *E* of *Fig. 3*, but after the relatively constant section at a negative potential it began to rise again to approach a new equilibrium at a higher positive potential. This may be interpreted by assuming that the Fe^{3+} added to the suspension was gradually removed possibly due to adsorption, then after reaching the adsorption saturation, the further $FeCl_3$ added to the solution increased the Fe^{3+} concentration again and consequently the potential as well. It can also be assumed, however, that the Fe^{3+} concentration and the potential decreases due to the hydrolysis proceeding in the initial section, but later with the increase of the H^+ concentration in consequence of the hydrolysis, this process will cease and the addition of further $FeCl_3$ solution increases the Fe^{3+} concentration again, causing a further rise in the potential.

However, interpreting the trend of curve *E* in *Fig. 3* on the basis of the above possibilities, the question arises why curves *b* and *e* in *Fig. 3* are of different character, though they also represent potential curves of suspensions of the same rock *E*, with the difference that in case of curve *e* the suspension contained 3% of the residual petroleum fraction after distillation above 350° C and in case of curve *b* 3% kerogen. From a comparison of the curve *E* with the curves *b* and *e* in *Fig. 3* it can be inferred that, taking into account the adsorption as a possible factor in the decrease of the Fe^{3+} concentration, the organic matter present, even without exerting an immediate reducing effect on the Fe^{3+} ions, in certain cases, depending on its character, may contribute to the constancy of the potential on a higher level, since in consequence of its more effective adsorption on the surface of the particles according to the supposition it will hinder the adsorption of Fe^{3+} ions and the decrease of their concentration and hereby also the decrease of the potential.

As a further and fairly conceivable possibility it can be suggested that the Fe^{2+} content in the samples may, at least as one of the several factors, contribute to the change of the potential by shifting the Fe^{3+}/Fe^{2+} ratio in favour of latter and so diminishing the potential. It should be noted that the rock samples investigated mostly contained carbonates and presumably it is the Fe^{2+} content belonging to carbonates which may play such a role, whereas the Fe^{2+} of the silicates present will be less effective in diminishing the potential. For instance, the potential of the suspension of sample *D* in *Fig. 1* became constant at a relatively high positive value; the carbonate content of the rock was insig-

nificant (CO_2 = 0.22%) and the FeO content, which in absence of carbonates may be present in silicates, was 1.09%. On the contrary, the CO_2 content of sample *A* in *Fig. 1* was 18.82%, its FeO content 2.45% and the corresponding values in sample *E* in *Fig. 3* were 8.96% and 2.96%, respectively. The assumable trend of the FeO content of the samples to influence the potential curves can also be seen from the data of Table 1.

Determination of the reducing capacity of the sediments on the basis of potential curves

According to the purpose of this paper it has been tried to characterize the reducing capacity of the samples studied by numerical value derived from the potential curves. A relative equlibrium seems to be reached in the case of most samples, thus the reducing capacity can be expressed by the quotient of the oxidizing agent consumed up to the reaching the equilibrium (expressed in Moles) and the potential change (expressed in Volts).

The potential curves of the suspensions of the rocks studied could be classified as belonging to three types according to the faster or slower decrease in potential after the initial potential rise. In assigning the curves to the groups, the quantities of oxidizing agent used (in ml), corresponding to the point where the decreasing section of the potential curve intersects the 0 mV line, were taken into account. The limit between groups I and II was arbitrarily

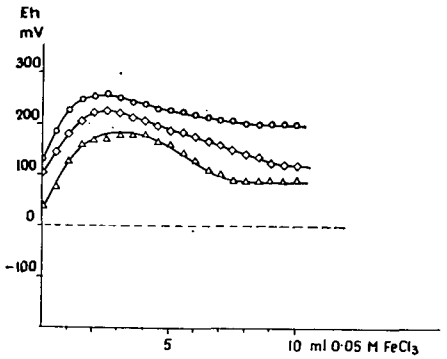


Fig. 6. Limiting and mean redox potential curves, respectively, characteristic of group III of the rock samples investigated.

chosen. The curves intersecting the 0 mV line below 5 ml consumption *(Fig. 4)* were assigned to *group I,* those intersecting this line above 5 ml consumption to *group II (Fig. 5),* whereas the potential curves which remained positive, at least under the conditions of the present investigations, were considered as belonging to *group III (Fig. 6).*

The mean values of the reducing capacity calculated from the curves grouped according to the above as well as the mean FeO contents of the groups are listed in Table 1.

TABLE 1

Mean reducing capacity and FeO content of sedimentary rocks grouped according to their potential curves

Type	$\frac{\Delta C}{\Delta E} \cdot 10^3$	FeO %	Number of samples
I	3.3	1.91	7
II	6.5	2.67	9
III	13.9	3.82	11

From these investigations of informative character it can be inferred that the reducing capacity of the samples markedly depends on their FeO content; the latter is, however, to be considered only as one of several factors and its effect prevails mostly, or its role in the change of the potential becomes more evident, if the other components also affecting the potential are present in less significant quantities or are absent.

SUMMARY

To assess the reducing capacity of sedimentary rocks, the potential curves of suspensions of powdered rock samples were determined using 0.05 M $FeCl_3$ solution as oxidizing agent and plotting the measured potential values the quantity of oxidizing agent consumed. Similar measurements were carried out with the same rock sample with 3 per cent of different organic matter added. The organic substances used as additives were kerogen, lignite and different fractions of petroleum distillation, respectively.

The change in potential can be brought into connection with the concentration of Fe^{3+} added to the suspension; the potential is, however, influenced by several factors in a different grade.

The potential of the suspension may decrease owing to the adsorption of Fe^{3+} on the surface of the particles, but the concentration of Fe^{3+} may also decrease by hydrolysis. If these processes were the only factors causing the changes in Fe^{3+} concentration and thus the decrease of Eh, it would be difficult to find connections between the potential curve and the reducing property of the rock.

If the possibility of the adsorption exists, organic substances may hinder the adsorption of Fe^{3+} by being more strongly adsorbed on the surface of the particles and contributing hereby to maintain the potential on a higher level, provided that the reducing effect of some other factor does not intervene. This, possibility is perhaps displayed by curve *D* in *Fig. 1* and curve *e* in *Fig. 3*.

Organic substances reducing the Fe^{3+} may also cause a decrease in potential, as shown e. g. in curves *c* and *d* in *Fig. 3*. Reducing sulphur-compounds or organic compounds forming complexes with Fe^{3+} may also lower the potential. Curves *b* and *a* in *Fig. 3* may be considered as examples of this effect.

Besides the possibilities mentioned, the role of Fe^{2+} present in this samples in determining the trend of the potential curves seems to be emphasized by the above investigations. This role in decreasing the potential may be primarily attributed to the Fe^{2+} of the carbonates; the role of the carbonates themselves cannot be neglected either, especially if they are present in very small particle

size and in fine distribution, as in most of the samples investigated. The very fine grain size increases the solubility and this process may also contribute to the decrease in concentration of the Fe^{3+} added to the solution by promoting its hydrolysis.

The above possible processes will determine in their mutual interaction the potential curves recorded in the suspensions and the reducing capacity determined by the method used. The reducing capacity was determined from the titration curves and was expressed by the quotient of the quantity of the oxidizing agent used to reach a relative equilibrium and the respective potential change. According to these informative measurements the Fe^{2+} content of the samples seems to play a role in determining the reducing capacity.

We intend to study the possibilities mentioned above by model-experiments, in order to obtain a more detailed picture on the effect and the interaction of organic and inorganic factors determining the reducing capacity of sedimentary rocks.

ACKNOWLEDGEMENT

The authors wish to express their sincere thanks to PROF. DR. L. CSÁNYI and DR. J. HORVÁTH for valuable discussions, to DR. J. MEZŐSI for the petrographical investigations, to MRS. C. LAKOS for microanalytical analyses, to MRS. M. AGÓCS for preparation of kerogene and to MRS. I. KISPÉTER for her technical assistance in the work.

REFERENCES

BOD, M., BÁRDOSSY, G. [1959]: A new method for the determination of the redox potential of sedimentary rocks. (In Hungarian) Geofizikai Közlemények *VIII*, 1—2, 53—65.

CSAJÁGHY, G. [1965]: A peloidok geokémiája, kémiai és fizikai tulajdonságai. (Geochemistry of peloids, their physical and chemical properties.) Manuscript, only in Hungarian.

DROZDOVSKAYA, A. A. [1963]: Application of new methods of determination of the oxidation-reduction potentials of rock in geological practice. (In Russian with an English resumé) Teoretitcheskie i Genetitcheskie Voprosi Mineralogii i Geochimii. Izd. Akad. Nauk Ukr. SSR, Kiev.

FORSMAN, J. P., HUNT, J. M. [1958]: Insoluble organic matter (kerogen) in sedimentary rocks. Geochim. et Cosmochim. Acta *15*, 170—182.

KRUMBEIN, W. C., GARRELS, R. M. [1952]: Origin and Classification of Chemical Sediments in Terms of pH and Oxidation — Reduction Potentials. Journ. of Geol., *60*, 1—33.

SHTCHERBINA, V. V. [1939]: Oxidation — reduction potentials as applied to the study of the paragenesis of minerals. (In Russian) Dokl. Akad. Nauk SSSR. *22*, 503—506.

STURGIS, M. B. [1936]: Changes in the oxidation — reduction equilibrium in soils as related to the physical properties of the soil and the growth of rice. Louisiana Agric. Exper. Stat. Bull., *271*, 1—36.

SZÁDECZKY-KARDOSS, E. [1955]: Geokémia. Akadémiai Kiadó, Budapest.

TRASK, P. D., HAMMER, H. E. [1935]: Degrees of reduction and volatility as indices of source beds. Drilling and Production Practice for 1935, 253.

ZOBELL, CLAUDE E. [1946]: Studies on redox potential of marine sediments. Bull. Amer. Ass. of Petroleum Geologists *30*, 4, 477—513.

PROF. DR. GYULA GRASSELLY
MISS DR. MAGDOLNA HETÉNYI
Institute of Mineralogy, Geochemistry and Petrography.
Attila József University at Szeged
Táncsics M. u. 2.
Szeged, Hungary

METASOMATIC PHENOMENA IN THE MÁTRA MOUNTAINS

J. MEZŐSI

INTRODUCTION

In areas of orthomagmatism one may repeatedly encounter rock alteration phenomena characterized by devitrification or possibly metamorphism of the groundmass and by the usual conversion of rock-forming minerals into hydrous neoformations. Also, potassium may happen to show considerable secondary enrichments. Thus the original, orthomagmatic, rock changes into a hypomagmatite and the andesite is replaced by various meta-rocks (hydroandesite, etc.), eventually by K-trachyte. It is a K-magmatism-like phenomenon rather than real potash-magmatism that one has to do with in the latter case.

Near the land surface, orthomagmas may acquire some potash character if the sedimentary rock traversed by the magma was rich in potassium. In such cases, transvaporisation takes place. When hot-water solutions migrate across an already-developed orthomagmatite, then dissolution and replacement are more considerable. Accordingly, this mobilization of potassium takes place close to the surface already. Potassium concentration may also increase when this element is bonded to mixed-layer clay minerals in a near-surface, acid or intermediary environment, while sodium and calcium are leached from the original rock.

In the last analysis, since hydrothermal solutions, as a rule, do not contain alkalis in substantial amount, in ascendent solutions they can be enriched solely by the exsolution of the alkali content of earlier-formed alumosilicates. Comparatively great amounts of alkalis can be introduced into ascendent solutions primarily during the weathering of feldspars.

THE ROLE OF ASCENDENT SOLUTIONS IN METASOMATISM

During metasomatic processes, in dependence on the quantity and quality of components dissolved in the ascendent solutions, the original rock can be differently altered. The solutions will either seep through the pores, or migrate upwards via fissures and joints. At Mátraszentistván locality, this latter is the case, so that infiltration metasomatism can be spoken of.

During the processes of the volcanic aftermath the original composition of the ascendent solutions may substantially change and the replaced paragene-

sis may differ considerably from the resulting, new mineral composition. According to KORZHINSKY [1959], the hydrothermal solutions show two extreme tendencies. One is the evolution of the solutions, the other the evolution taking place in the magma chamber, where a fractional distillation of residual solutions occurs. In both cases hydrothermal parageneses of different composition will develop.

In the course of infiltration metasomatism the ascendent solutions rise via joints and fissures produced by tectonic movements. Considering that the effect of the solutions is felt even farther away from the fissures, the influence of the country rock cannot be disregarded. Accordingly, if an ascending hydrothermal solution is taken to be of definite composition and governed by either of the above two tendencies, it is merely the ions exsolved from the country rock that will provoke additional substantial changes. Along with the formation of new, usually volatile-rich, minerals, the chemical composition of the rock may also change substantially. Therefore it is not uninteresting to study the rock sequence crossed by the solutions.

Considering the geological structure of the western Mátra Mountains, the following formations can be reckoned with. The crystalline basement seems to be overlain by Oligocene rocks which, though in reduced thickness, are known to be exposed near Nagybátony, in the northern foreland of the Mátra Mountains. In these Oligocene (Chattian) sandstones the share of glauconite can attain even 10%. Since glauconite is a potassium-containing hydrosilicate, so under proper conditions this mineral may become one of the sources of potassium accumulation. According to well-known chemical analyses, the K_2O content of the Burdigalian "Lower Rhyolite Tuff" varies between 3.22 and 3.47%, this value being considerably higher than the average K_2O content of the andesites of that region. The 40- to 60-m-thick dacite tuffs of the Helveto-Tortonian boundary have a potassium content similar to that of the rhyolite tuffs of the Burdigalian sequence. The K_2O contents of the Helvetian and Lower Tortonian andesites vary between 1.2 and 2.6%, being always lower than the value of Na_2O. Inasmuch as a hydrothermally altered rock is considered, the K_2O content may be as high as 5.5% (near the KIOSZ mansion at Mátraszentistván). In this case mainly illitization seems to be responsible for the high K_2O content [MEZŐSI, 1968]. On the basis of the boreholes Gyöngyösoroszi—2 [KUBOVICS, 1964] and Mátraszentimre—2 [MRS. CSILLAG, 1968] it seems probable that these formations are available beneath the andesite complex throughout the western Mátra Mountains. Therefore, in this territory abundant sources of potassium can be reckoned with.

As regards the geological structure of the territory, it could be stated that the area affected by metasomatism belongs to a NW—SE-trending system of faults, forming a part of the heavily block-faulted sequence occurring in the vicinity of Nagybátony [MEZŐSI, 1969]. Along fissures and faults, alteration is more pronounced.

On the basis of the results of air-spectrometric surveying, WÉBER and GÉRESI [1970] showed the vicinity of Mátraszentistván to be an area where the potassium content is comparatively higher, K-metasomatism associated with volcanism being more pronounced there. These authors also showed the highest concentrations of potassium to be controlled by tectonic zones. Thus an earlier statement of the present writer [1968] has been confirmed by investigations of this kind.

The ample variety of the manifestations of metasomatism in the area under consideration can also be explained by the fact that the front of metasomatism does not shift with constant velocity. On one hand, this is due to the extremely irregular variation of the texture, composition and porosity of the rock owing to the random distribution of thin lava flows and interbedded tuff layers; on the other hand, it is due to the presence of fracture lines. Therefore there is no real zone of replacement in which the same mineralization could develop.

Because of the low concentration of ions in the migrating hydrothermal solutions the rock-dissolving effect of the solutions will be considerable. Solution is also promoted by the comparatively higher temperature — a factor which can always be reckoned with in the course of hydrothermal metasomatism.

Grain size also influences the dissolution of minerals. In general, solubility increases with decreasing grain size. This can be explained by the fact that on the grain surface the number of ions of unbalanced charge increases greatly as compared to the unbalanced ions inside the crystal. Thus if the dissolution of the mineral grains of a clastic rock were examined in comparison to the crystals of different size of a magmatic rock, one would find that in the clastic rock the same mineral is dissolved more easily, i. e. an alkali is leached from the sanidine fragments of rhyolite tuffs or from the glauconite of sandstones more easily than from a relatively intact crystal component of magmatites.

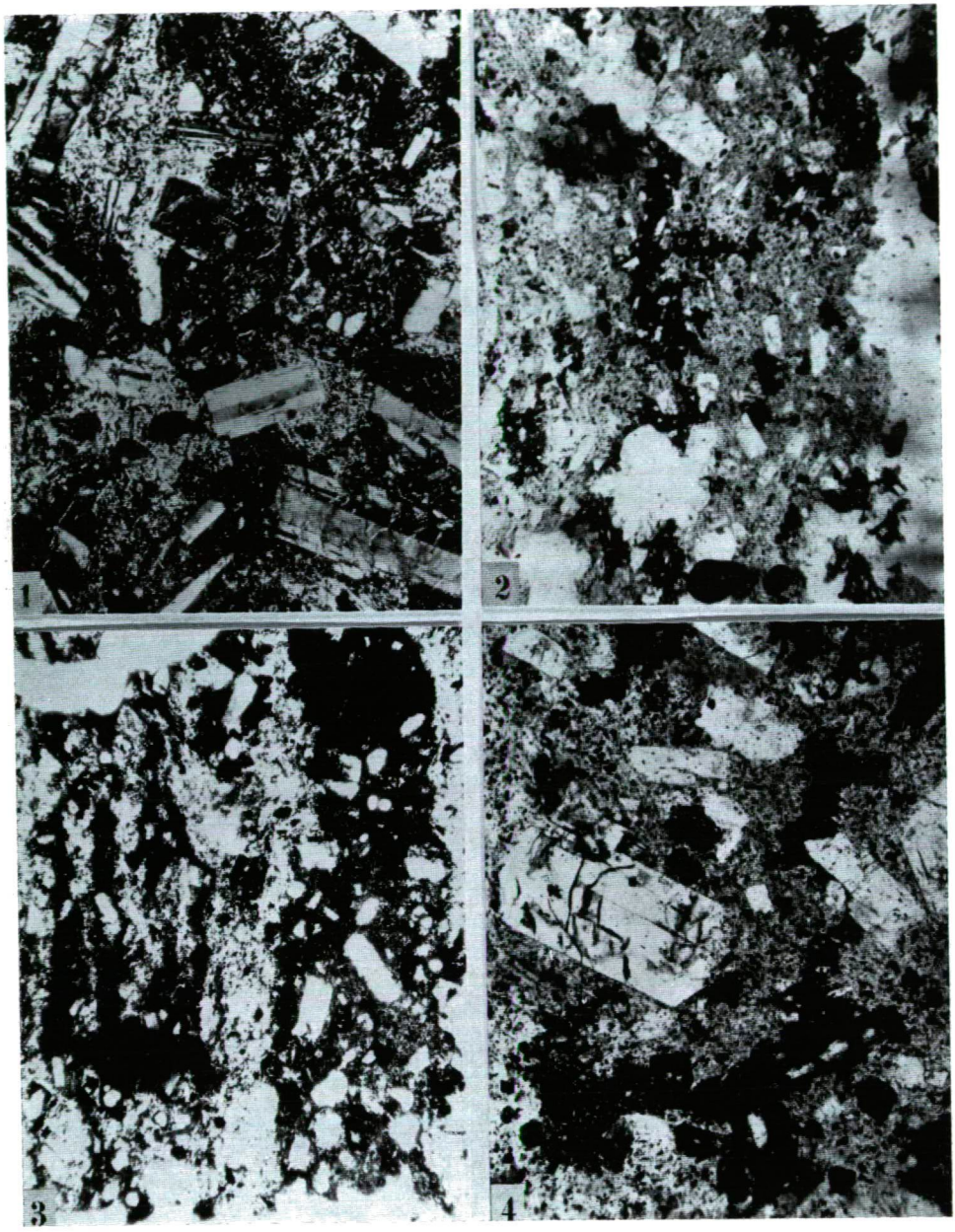
THE PROCESS OF ZONATION

During dissolution, reactions may set in, provoking a change in the concentration of H^+-ions, reactions playing an important geological role in the solubility behaviour of mineral compounds. In addition to this, the variation of pH influences the valency, i. e. the degree of ionization. On the other hand, an increase in pH will promote oxidation — an important geochemical factor during metasomatism.

As shown by KORZHINSKY's investigations [1959], the solutions first show an increasing acidity as manifested by autometasomatic reactions of comparatively higher temperature. In the course of their slow migration the solutions will react with the country rock and their acidity will thus gradually decrease. The leached substances and/or the precipitated components will exhibit a zonation. In the direction of migration, i. e. away from the fissure or joint, the following zones can be distinguished: *1.* a zone of increasing acidity, where the rocks are exposed to leaching and where precipitation is insignificant, *2.* a zone of maximum leaching with mineral precipitations, and finally, *3.* a zone of decreasing acidity with a decline of leaching and an increase of mineral precipitations. In the last analysis, the development of zonation is a natural process.

In his classification of infiltration metasomatism SZÁDECZKY-KARDOSS [1958] preserved the above tripartite division. Proceeding from the ore body towards the magmatite, he distinguished: *1.* an ore-bearing zone, *2.* a silico-magmatite zone and *3.* a hydromagmatite zone. Under special conditions this zonal pattern may change.

The occurrence of zonation has been observed in Hungary, too. Thus V. SZÉKY-FUX [1964] showed the presence of kaolinization with a low con-



Figs. 1—4.

centration of precious metals in a reduced vertical, and greater lateral, extension close to the surface at Telkibánya, North Hungary. At 400 to 500 m depth the function of kaolinite is taken over by montmorillonite containing somewhat richer ore mineralization. Wherever the fissures or joints are closely spaced, the original ortho-rock has been totally altered into andesitogenic propylite. Where spacing is wider, there relics of fresh ortho-rock may occur between the fissures or joints.

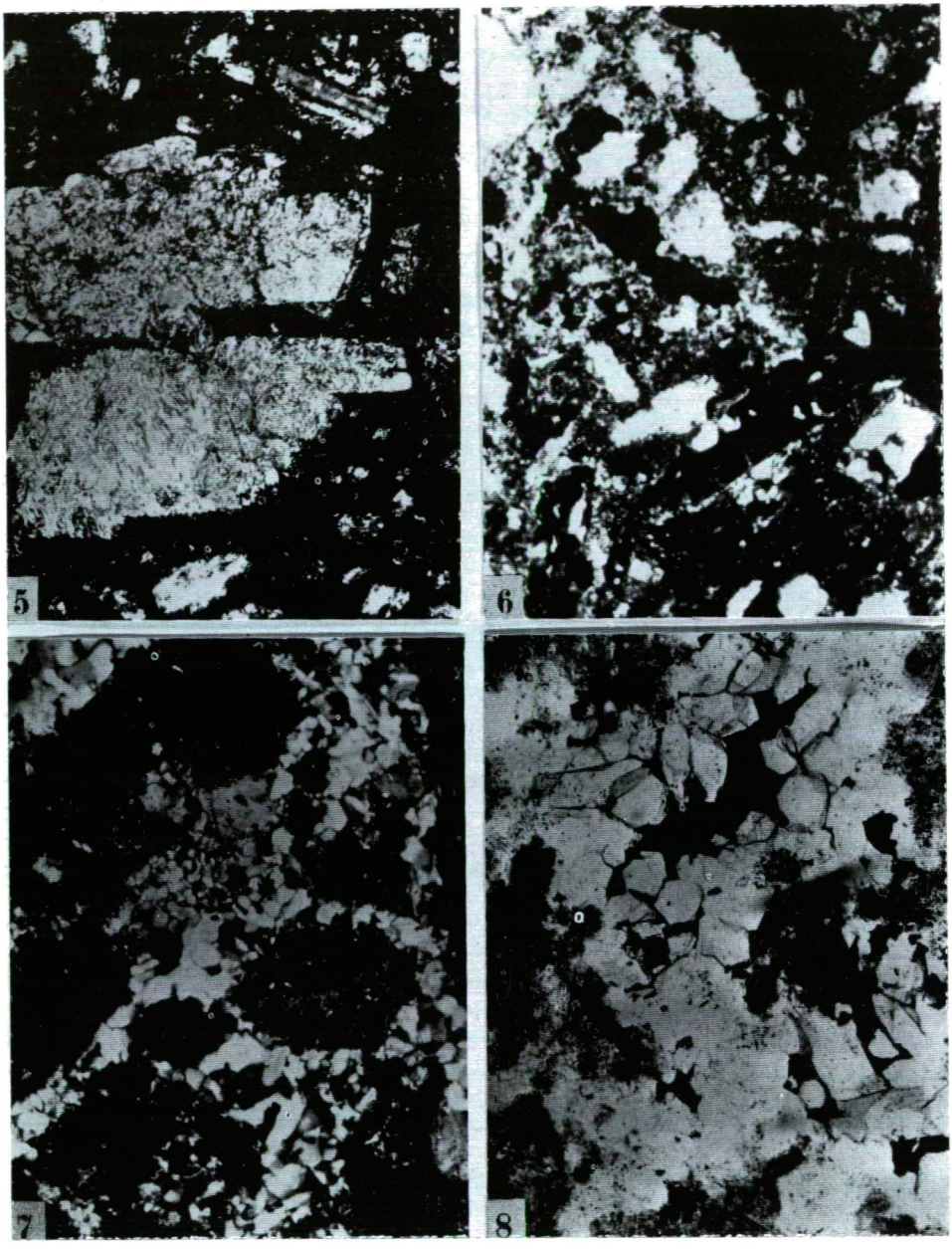
Zonation can also be shown to occur in a dike at Mátraszentimre [NAGY, BARBÁCSI, 1966]. On both sides, the dike is similarly altered in a width of some 50 m. The plagioclases of the country rock are completely sericitized, the pyroxenes are chloritized or they have been totally dissolved out of the rock. In the cavities, precipitations of silica gel can often be observed. Close to the dike, the country rock is heavily silicified. Away from the boundary of this zone, over a distance of about 80 m, the feldspars are still sericitized, but the pyroxenes have remained fresh.

A zonation can also be caused by the variation of both the temperature and composition of the fluctuating solutions. On Mt. Hidegkút, western Mátra Mountains, KUBOVICS [1966] discovered K-metasomatism of comparatively higher temperature as manifested by the formation of sanidine, adular, glauconite, seladonite and zeolite. The lower-temperature phase has produced mainly SiO_2 modifications.

EXAMINATION OF THE ROCK WITH MICROSCOPE AND DERIVATOGRAPH

In the metasomatic alteration of the andesites of Mátraszentistván a kind of regularity, developmental sequence, can be recognized. The fresh or just slightly altered rock is of dark-grey colour with red ochreous bands of just a few mm width running parallel to the surface or along the joints. The rock of this kind is compact, the feldspars in it being fresh, with bright, glistering joint planes. As shown by the microscopic image of the rock, the groundmass has acquired a mottle-patterned habit in the initial stage and the lighter parts have lost their magnetite content. At the same time, the groundmass has been more or less devitrified *(Fig. 1)*. Using just one nicol, one can readly observe that the magnetite grains have been dissolved and the ore has been concentrated along the joints *(Fig. 2)* or, eventually, that it has stained the groundmass in a zonal pattern *(Fig. 3)*. At this stage the feldspars are still fresh, twinning and zoning being quite distinct upon them. However, the alteration of pyroxene does set in. In fact, pyroxene has been totally replaced by seladonite, fibrous, slightly pleochroic, forming pseudomorphs in many cases *(Fig. 4)*. The alkali content of a rock of this kind does not change yet essentially, the increase of potassium content may still be quite insignificant (Table I). The feldspars of such rocks may be completely sericitized either partly as a result of the effect of surface agents, or under the influence of hydrothermal solutions *(Fig. 5)*. This is partly responsible for the higher potassium content observable in such cases.

Fig. 1. Devitrified, mottled groundmass, + N, 80×
Fig. 2. Ore concentration in the mottles of the mottlepatterned groundmass, 1 N, 32×
Fig. 3. Zonal ore accumulation, 1 N, 32×
Fig. 4. Fresh feldspar associated with seladonitic pyroxene, + N, 80×



Figs. 5—8.

Silicification is first manifested when the feldspars are still comparatively fresh and when the femic components already show an advanced ore mineralization *(Fig. 6)*. Quartz either shows an irregular mode of occurrence, often dissecting the groundmass in a net-like pattern *(Fig. 7)*, or it forms crystals of hexagonal cross-section grown on the walls of cavities in the rock and filled up additionally by limonite *(Fig. 8)*. Leaching may lead to an increase of porosity, i. e. to the formation of cavities of different size. First of all, limonite precipitated on the walls of the cavities and then their inner space was filled up by fine-grained chlorite which has been identified as pennine. In such cases the pennine aggregate is surrounded by an ore frame *(Fig. 9)*. Sometimes, not only the femic mineral, but also the altered feldspar is ore-framed *(Fig. 10)*.

TABLE 1

Sample number	rock habit	Na_2O%	K_2O%
1.	ochre-yellow, slightly porous	0,72	11,50
2.	pinkish to ochre-coloured, porous	0,10	10,80
3.	reddish to ochre-coloured, porous	0,58	10,09
4.	dark-grey, compact	2,25	2,18
5.	greyish-pink, slightly porous	0,40	11,30
6.	pinkish to light-grey	0,05	10,10
7.	reddish to purple, slightly porous	0,10	10,57
8.	grey, compact	2,89	2,53
9.	pink, slightly porous, with yellow and white mottles	0,10	9,65
10.	purple to pink, compact	0,30	10,99
11.	pink, slightly porous, with white and yellow mottles	6,10	6,10
12.	dark-grey, compact, with ochreous bands	2,90	3,36
13.	dark-grey, compact	2,65	2,66
14.	dark-grey, compact, with a thin oxide coating	1,25	8,53
15.	grey, slightly porous, with pink bands	0,35	12,00

In orthomagmatites the degree of oxidation increases under the influence of hydrothermal solutions and magnetite develops into γ-Fe_2O_3 which is known from earlier investigations [MEZŐSI, 1967]. The magnetite lattice develops into a hematite lattice rather easily. In fact, with additional metasomatic effect, the iron may be precipitated as iron(III)-hydroxide in fissures or joints at the level of the oxidation zone. Iron(III)-hydroxide may, on its turn, develop into goethite. Accordingly, on account of the behaviour of iron the bleaching, discolouring of the rock corresponds to the final phase of metasomatism. Also, this is the reason why the femic minerals, if any, are often subordinate in such rocks.

The nature of the iron oxide phase precipitated under metasomatic effect is also indicated by the following results of analyses. Of the powder of a porous, reddish to ochre-coloured rock a derivatogram was made. The total iron content of the rock was found to be 4.58%, of which the share of Fe^{2+} was as low as 0,7% *(Fig. 11)*. Between 70 and 200°C the DTA curve showed

Fig. 5. Sericitized feldspar pseudomorph, + N, 80×
Fig. 6. Ore-mineralized, thermal mineral with accumulation of quartz, + N, 80×
Fig. 7. Groundmass impregnated by quartz in a net-like pattern, + N, 80×
Fig. 8. Idiomorphic quartz accumulated in cavities, 1 N, 80×

some weight loss which on the TG curve corresponded to a weight loss of 0.45%. In correspondance with this, an endothermic peak appeared on the DTA curve as a result of water lost partly by clay minerals, partly by adsorption. At 310°C on the DTG curve, again, a pronounced weight loss

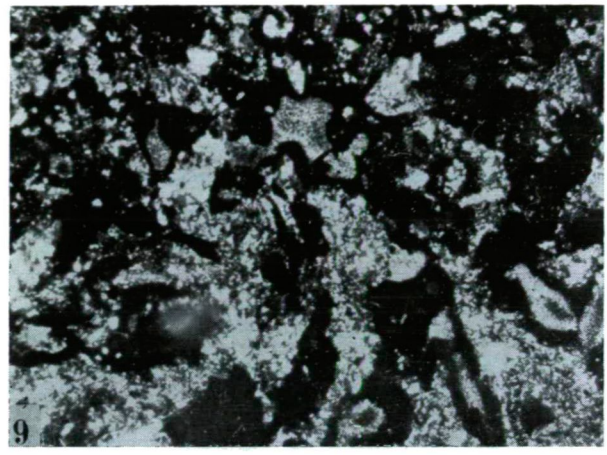


Fig. 9. Rhytmical precipitation of limonite and pennine in cavities, + N, 80×

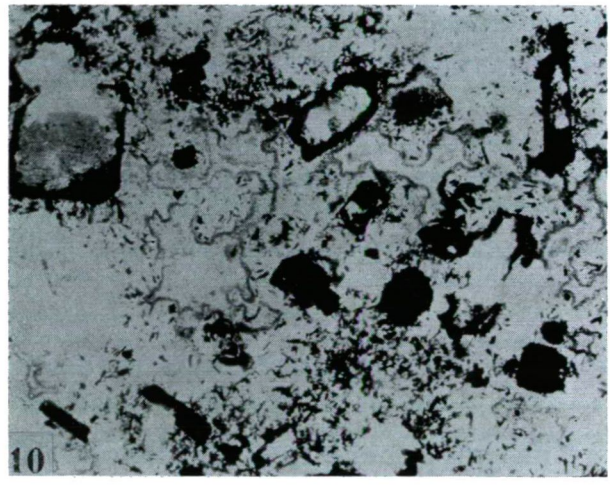


Fig. 10. Ore-framed, altered feldspar in porous rock, 1 N, 80×

presents itself which corresponds to 0.78% as measured on the TG curve. However, on the exothermic peak appearing at 350°C on the DTA curve an inflexion appears at 310°C. Properly, here an endothermic reaction is concealed by an exothermic one. The exothermic reaction is the alteration of goethite into γ-Fe_2O_3 showing two exothermic peaks — one at 310°C, one at about 540°C, a phenomenon indicating the alteration of this modification.

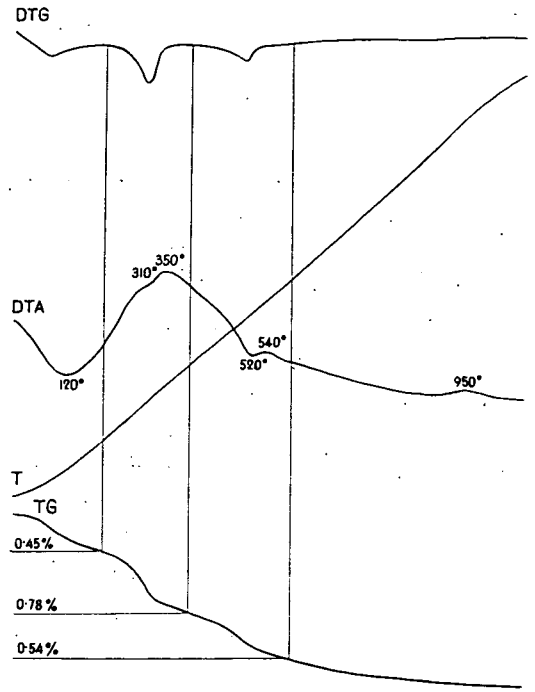


Fig. 11. Derivatogram of metasomatized andesite

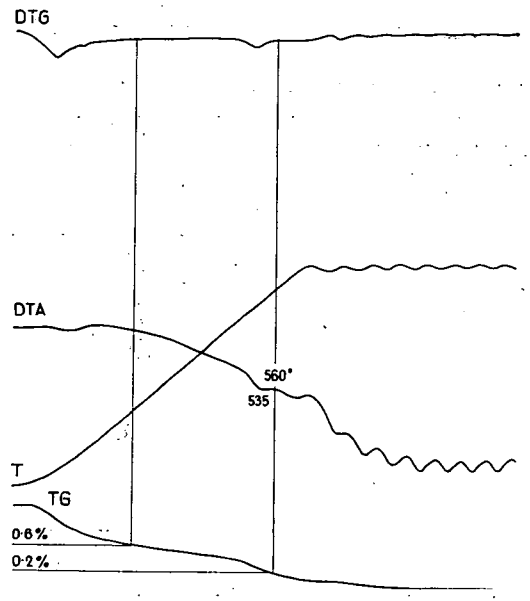


Fig. 12. Derivatogram of metasomatized andesite held at a temperature of 400°C

This could also be proved by that the curve, obtained for the sample at 400°C, showed nothing else than the higher exothermic peak of the alteration $\gamma \rightarrow \alpha$, i. e. a change in modification no longer accompanied by any change in weight. However, a weight loss of 0.2% due to water released during the break-down of the illite structure could still be observed within the 480° to 560°C range *(Fig. 12)*.

As referred to earlier, when plagioclase is replaced, the mineral gets first mottled, then it is deprived of both the zonal structure and twin intergrowth characteristic of orthoandesites of normal development.

Since in the course of andesite metasomatism the species of feldspar corresponds more or less to the labradorite series, let us quote LAGACHE's [1965] experiments in a few lines. He examined the dissolution of labradorite, albite and adular at different temperature and CO_2 pressure under the conditions of identical specific surface area.

During his experiments LAGACHE came to the following conclusions. Alkalis are the most easily soluble elements. The concentration of alkalis in solution increases as a function of time, being proportional to the surface area of the crystal exposed to solution. With a rise in temperature and CO_2 pressure, the rate of dissolution will increase. Silicium behaves differently. Initially the rate of its dissolving is higher than that of alkalis, but after attaining saturation, it does not show any substantial change anymore. The saturation limit is slightly influenced by the species of feldspar, by temperature and by the pressure of CO_2. Testing albite and adular, he used also such a method in which at the end of a given time unit the solution was decanted from the sample being tested and the sample was again diluted with distilled water. After fivefold repetition no substantial difference in the quantity of dissolved substance could be observed (in case of albite 28.6 — 31.0 ppm Na_2O and 159—183 ppm SiO_2, in case of adular 24—29 ppm K_2O and 112—140 ppm SiO_2). In connection with this change, it should be borne in mind, that in the fourth and fifth cases the surface was in a heavily dissolved state — hence the lower value. Aluminium, practically, was not dissolved at all.

With labradorite, the same could be observed as in the case of albite or adular in respect of the dissolution of sodium, aluminium and silicium. Calcium, however, precipitated in the form of calcite which was quite logical under the given experimental conditions.

As shown by quantitative analyses, adular was dissolved most slowly, albite most rapidly. The rate of dissolution first shows an exponential rise, later a marked decline.

The plagioclases of the labradorite series do not represent a stable state, as notified also by LAVES [1960] who drew the conclusion that no feldspar of stable phase could be expected to occur between An_{30} and An_{70}.

As confirmed experimentally by WYART and SABATIER [1956], at a relatively low temperature (500°C and at a pressure of 600 bar), an orthoclase, treated by an aqueous solution of NaCl, will change into albite. However, in the case of anorthite a replacement of this kind was impossible. Albite, in turn, did alter into microline at 350°C upon treatment by aqueous KCl solution. Accordingly, Na and K are easily interchangeable, but for an exchange of Ca, the Si/Al ratio must change, too.

Consequently, the above investigations confirmed the assumption that during metasomatism, under proper conditions, labradorite alters into albite rather easily and that albite, on its turn, does so into sanidine.

In the course of K-metasomatism, when plagioclase was replaced, a zonal structure rather than a mottled pattern could be observed in certain cases. Investigating the causes of the two different forms of appearance, the present writer has come to conclude that at certain orientation the labradorite replaced by sanidine will always become zoned, at some other orientation, mottled. Precisely, when the cross-section was perpendicular or subperpendicular to crystal axis *b*, the zonal structure was observed, at orientations other than this the mottled pattern appeared *(Fig. 13)*. The zones were always

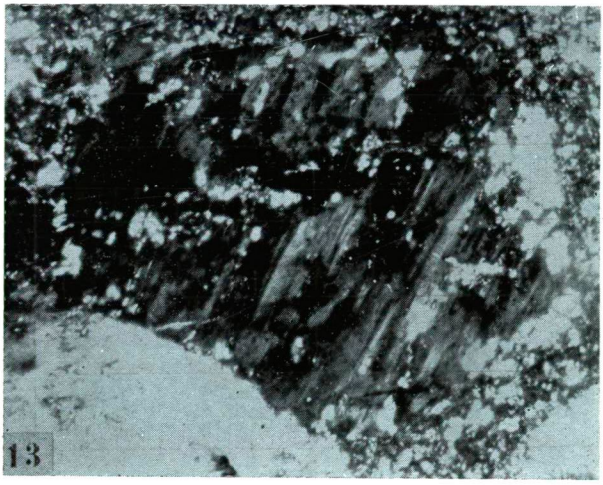


Fig. 13. Zoned feldspar. + N, 200×

parallel to face *001*. As for feldspar structures, it is well-known that in the direction of crystal axis "*a*" there are chains in which the cations of the second order are situated. Hence, it looks probable that the zones exhibit structural elements connected with metasomatic replacement, elements which can be visualized optically.

BAMBAUER and LAVES [1960] observed a zonal structure in adular. This, however, was due to slow growth and the individual zones showed different degrees of arrangement.

X-RAY ANALYSES

Numerous X-ray diffractograms were made of bulk rock and selected samples (26 kV, 18 mA, CuKα radiation). The interpreters of these had to answer the following questions: Can the degree of alteration be traced in the bulk samples of differently metasomatized rocks? Which of the characteristic lattice planes are expected to occur on the diffractogram of a comparatively fresh rock? Which planes of the lattice can be considered characteristic of a metasomatized rock.

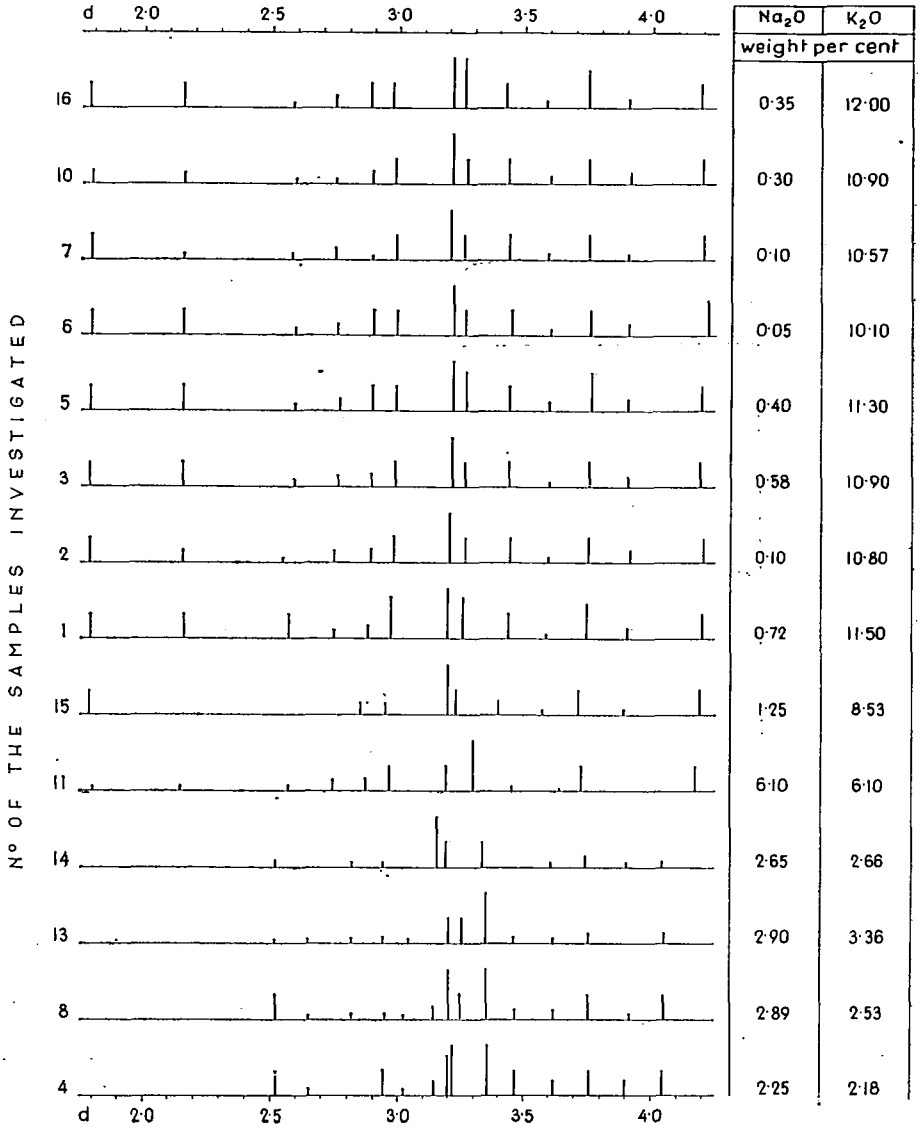


Fig. 14. d values of test samples as referred to feldspar

Considering the results of Corlett and Eberhard [1967], one can point out that lattice planes *131* and $\bar{1}31$ were always present on the X-ray diffractograms of those rock samples which were of dark-grey colour, which contained fresh feldspar and which could be considered to represent an ortho-rock even from the point of view of alkali content. On the basis of the difference in the 2 Θ value of the two lattice planes a plagioclase containing *An* in 50 to 60% could be identified. With the appearance of sanidine, plane $\bar{1}31$ will vanish.

According to CALLEGRI and DE PIERI [1967], the value of d_{201} can be of use for the determination of the sodium content of sanidine. In the test samples the corresponding d value varied between 4.15 and 4.23, a fact hinting at the presence of a transition between sodium- and potasium-rich members, with 10 to 20% *Ab*. The results of BOWEN and TUTTLE [1950] led to similar interpretation.

Fig. 14 shows the d values of a few samples as referred to feldspar. The size of the lines is proportional to the value of intensity. The numerals are serial numbers of test samples. In the tabulation the Na_2O and K_2O contents of the samples have also been shown.

During the interpretation of X-ray diffractograms the degree of Si/Al arrangement could also be assessed. If this value was about 1.6 there was just an inversion point among the elements of symmetry. In this case the planes d_{hkl} of higher intensity were split up into planes of lower intensity. Consequently, the line corresponding to the value of *131* and $\bar{1}31$ *d*, or the lines $24\bar{1}$ and $\bar{2}41$, respectively, made their appearance. However, because of the statistical degree of Si/Al arrangement the plane of symmetry parallel to face *010* appeared with 6% K_2O already (the angle formed by faces 001 $\wedge$ 010 being then as high as 90°), and the splitting of the planes d_{hkl}, d_{hk0} and d_{0kl} ceased. Consequently, the planes $\bar{1}31$ and $\bar{2}41$ must also have missed. Since sanidine shows an excellent jointing along planes *0k0* and *001*, because of the plane of symmetry, the planes *040*, *060* and *001* have come even more into prominence and their intensity too was comparatively high. Still absent in labradorite, the high-intensity line *060* is always present in the case of sanidine. In this latter the plane $\bar{2}04$ was always represented by a high intensity, whereas it was absent in labradorite. It could also be observed that the increase of symmetry was accompanied by an increase in the d value of lattice plane $\bar{2}01$.

In the last analysis, it can be concluded that the metasomatic replacement of feldspars can be analysed by X-ray methods. Since higher potassium content is often indicative of ore accumulation, the above results are also important from the practical point of view.

SUMMARY

The variation of the composition of ascendent solutions is greatly influenced by the geological sequence intersected. In the western Mátra Mountains, glauconitic sandstones, rhyolite tuffs and dacite tuffs are of interest from this point of view. Along fracture lines, the ascendent solutions provoke more or less heavy alteration of the rock, bringing about an infiltration metasomatism. During metasomatism, along fracture lines a zonation corresponding to the degree of alteration will develop.

In the process of metasomatic alteration of the Mátraszentistván andesites some regularity can be observed. At the initial stage the groundmass of the fresh, dark-grey andesite becomes mottle-patterned, being more or less devitrified. At the same time, the magnetite grains are dissolved. At this stage, feldspars are still fresh (intact), whereas pyroxenes are replaced by sanidine, fibrous, slightly pleochrous. Silicification usually sets in when the femic components already show a high degree of metallization. As for quartz, it is either

irregularly scattered, or dissects the groundmass in a net-like pattern. On account of leaching, porosity may increase and in such cases quartz may appear grown freely on the walls of cavities. During K-metasomatism, plagioclase is sometimes zoned rather than mottle-patterned. These zones run parallel to face *001*.

As observed by the present writer while interpreting X-ray diffractograms, with an increase of potassium content the conditions of symmetry also changed, the splitting of the d_{hkl} planes ceased and lattice planes *040*, *060* and *002* manifested themselves with high intensity.

REFERENCES

BAMBAUER, H., LAVES, FR. [1960]: Zum Adularproblemen. Schweiz. min. und. petr. Mitt., *40*, 177.

BOWEN, N. L., TUÊTLE, O. F. [1950]: The system $NaAlSi_3O_8$—$KAlSi_3O_8$—H_2O. The Journal of Geology *58*, 489.

CALLEGARI, E., DE PIERI, R. [1967]: Unmixing in the sanidines of the "Pietra Verde" of the Dolomites (Italy). Schweiz. min. und petr. Mitt., *47*, 111.

CORLETT, M., EBERHARD, E. [1967]: Material für chemische und physikalische Untersuchungen an Plagioklasen I. Schweiz. min. und petr. Mitt., *47*, 303.

CRISTOPHE, M., LÉVY, M. [1967]: Sur le mécanisme de „l'échange" Na—K par voie hydrothermale dans l' albite. Bull. Soc. franç. Minér. Crist., *90*, 411.

CSILLAG-TEPLÁNSZKY, E. [1968]: A Mátraszentimre 2. sz. alapfúrás földtani eredményei. MÁFI Évi Jelentése 1966-ról, 197.

KORZHINSKY, D. S. [1959]: The advancing wawe of acidic components in ascending solutions and hydrothermal acid-base differentiation. Geochemica et Cosmochimica Acta 1/2. p. 17.

KORZHINSKY, D. S. [1965]: Abriss der metasomatischen Prozesse. Akad. Verlag, Berlin.

KUBOVICS, I. [1964]: Jelentés a Gyöngyösoroszi 2. sz. fúrás kőzettani, geokémiai vizsgálatáról. Manuscript. MÁFI Adattár.

KUBOVICS, I. [1966]: A kálimetaszomatózis szerepe a nyugat-mátrai kőzetképződésben. Földt. Közl., *96*, 13.

LAGACHE, M. [1965]: Contribution a l'étude de l'altération des feldspaths dans l'eau entre 100° et 200°C sous diverses pression de CO_2 et application à la synthèse des minéreaux argileux. Bull. Soc. franç. Minér. Crist., *8*, 223.

LAZARENKO, E. K. [1966]: Über Probleme der Vererzung in den Sowjet-Ostkarpaten. Acta Geologica *7*, 173.

LAVES, F. [1960]: Al/Si Verteilungen, Phasen Transformationen und Namen der Alkalifeldspäte. Zeitschr. f. Krist., *113*, 265.

MEZŐSI, J. [1967]: Contribution to the knowledge of the magnetite-hematite system of oxivolcanites. Acta Miner. Petr., *18*/1, 23.

MEZŐSI, J. [1968]: Potassium metasomatism in the neighbourhood of Mátraszentistván. Acta Miner. Petr., *18*/2, 79.

MEZŐSI, J. [1969]: Tectonics of the Nortwestern slope of the Mátra Mountains. Acta Miner. Petr., *19*/1, 45.

NAGY, B., BARBÁCSI, A. [1966]: A mátraszentimrei ércesedés ásványgenetikai vizsgálata. MÁFI Évi Jelentése 1964-ről, 403.

SZÁDECZKY-KARDOSS, E. [1953]: Geokémia. Budapest.

SZÁDECZKY-KARDOSS, E., VIDACS, A., VARRÓ, K. [1958]: A Mátra hegység neogén vulkanizmusa. MTA Geokémiai Konf. Munk.

SZÁDECZKY-KARDOSS, E. [1959]: Über die Migrationserscheinungen magmatischer und metemorpher Geisteinsbildungsprozesse. Freiberger Forschungsh., *58*, 66.

Széky-Fux, V. [1964]: Propilitesedés és kálimetaszomatózis a Tokaji hegységi vizsgálatok tükrében. Földt. Közl., *94*, 409.
Wéber, B., Géresi, Gy. [1970]: A kálium eloszlása a Mátra hegységben légi gammaspektrometriai felvétel alapján. Földtani Közl., *100*, 77.
Wyart, J., Sabatier, G. [1956]: Mobilité des ion alcalins et alcalino terreux dans les felspaths. Bull. Soc. franç. Minér. Crist., *79*, 444.
Wyart, J., Sabatier, G. [1958]: Mobilité des ion silicium et aluminium dans les cristaux de felspath. Bull. Soc. franç. Minér. Crist., *81*, 223.

Doc. Dr. József Mezősi
Institute of Mineralogy, Geochemistry
and Petrography
Attila József University at Szeged
Táncsics M. u. 2.
Szeged, Hungary

RELATIONSHIP BETWEEN GRAIN SIZE AND HEAVY MINERALS CONTENT

B. MOLNÁR

INTRODUCTION

A river has a definite drainage area and the sediment deriving from it reflects the lithology of the source area. Sediments transported by large rivers usually mostly exhibit substantially different compositions. The differences in the composition of deposited sediments do not only facilitate to distinguish different facies, but also permit to determine the distribution in space of juxtaposed and superimposed sequences of identical and/or different origin.

As a matter of course, the lithological conditions of the drainage area are reflected by the micromineralogical composition of river-transported (or -deposited) sands, particularly so, by the assemblage of minerals of a specific gravity greater than 2,88 — the so-called heavy minerals.

Heavy mineral analyses are often used in geological investigations. A number of applications other than locating source areas are known. For instance, if used in ore prospecting by drilling in a grid pattern, they promote the determination of trends in metallization. Coal prospectors can use the characteristic heavy minerals compositions of barren rocks for the identification of coal seams. Hydrocarbon prospectors can use the method for locating reservoir structures; prospectors for subsurface waters can locate aquifers on the basis of the same results.

In many cases, single heavy minerals play the role of tracers associated with the commercial mineral being prospected. As a matter of fact, they are more common — and possibly more easily determinable — than the latter, thus being of good help in locating the deposit being prospected. An additional application is to use the method for studying the history of palaeohydrography of an area or for separating sedimentary and pyroclastic members within a sedimentary sequence.

Despite the multitude and high frequency of applications, many workers suspect that potential errors may lead to distortion of facts. Criticism against the distorting effect of changes in grain size has been enounced by a particularly great number of authors. Accordingly, when always the same fraction of sediments of identical origin is examined (what is mostly the case in routine work), the results obtained may prove different for a sediment of fine grain

size and for a coarse-grained one. This fact, however, may lead the student to assume suggest different source areas for the two cases.

Not even the most important relevant papers do discuss this problem in sufficient detail. The interrelations of grain size and the abundance of quartz, magnetite and tourmaline — i. e. of three minerals only — were discussed theoretically, as deduced from STOKES' law, by W. W. RUBEY, [1933]. As shown by that author, magnetite having a high specific weight appears in the finest layer of a sediment of the 0,125 to 8,0 mm size range as early as the sample still lacks quartz, a mineral of lower specific weight. Magnetite has its concentration peak in the finer grained fraction (0,6 mm ∅), whereas quartz has it in the coarser one (1,0 mm ∅). The specific weight of tourmaline is intermediate between the two former minerals, thus its concentration peak can be found, correspondingly, between the two — at 0,9 mm ∅.

L. HAWKES and A. J. SMYTHE, [1931] examined the quantitative changes of the minerals of sea-shore sands of the 0,127 to 0,317 mm grain-size range as distributed among the different fractions. It is interesting in the results of these authors that garnet, though having a specific weight higher than that of feldspar and quartz, tends to increase towards the coarser fractions instead of doing so towards the finer ones, a fact probably due to the particular character of the source area and to the higher resistance of garnet. The investigations of A. VENDL, [1954] were confined to the relationship of grain-size and mineral composition of materials finer than sands, chiefly clays.

Other papers touching upon the subject include but occasional hints at relations between grain composition and heavy mineral composition [J. K. HSU, 1960; F. P. SHEPARD and D. G. MOORE, 1960; F. P. SHEPARD, 1960; A. MIRSKY, 1961; R. L. MCMASTER, 1962; T. H. VAN ANDEL, 1964/a, 1964/b; A. KODYMOVÁ, 1966].

The present paper aimes at contributing to the solution of the problem and at selecting, on the basis of the information available, that grain fraction whose analysis may yield the most reliable and valuable data as to the characteristics of the heavy mineral composition.

SAMPLING

In the present study preference had to be given to samples deriving assuredly from one and the same source area, comprising a wide range of size fractions and the greatest possible number of heavy minerals. What may fit

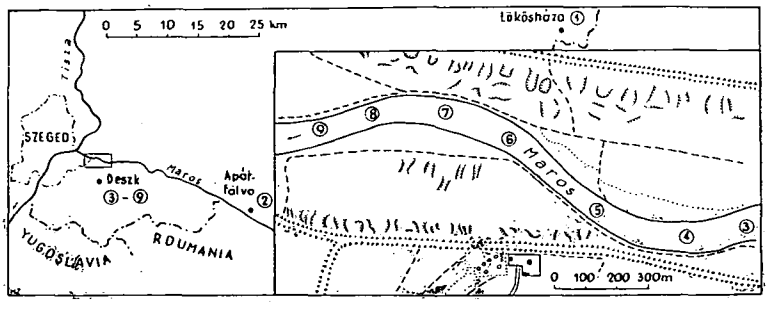


Fig. 1. Location map of sampling points

this condition best of all seems to be sediment transported and or deposited by a present-day river. Our choice fell on the Maros River [B. MOLNÁR, 1964/a; 1964/b].

Sample No *1* was collected at Lőkösháza, at 120 km or so from the mouth, from Latest Pleistocene deposits of the Maros River *(Fig. 1)*. The source area of the river has not changed since the end of the Pleistocene [B. MOLNÁR, 1964/b, 1965/b]. Thus the coarser grain fraction, absent in the river bed, could be sampled here and used for the present analysis. Sample No *2* was taken in the river bed, at 50 km from Apátfalva; Samples No *3* to No *9* were taken in the river bed at Deszk, 3 km away from the mouth *(Fig. 1)*.

GRANULOMETRIC ANALYSIS

The samples were analysed by sieving, and Sample *9* was also examined by the method of hydrometry. The results are shown in *Fig. 2* and Table I. The median diameter *(Md)* of the nine samples varies between 0,073 and

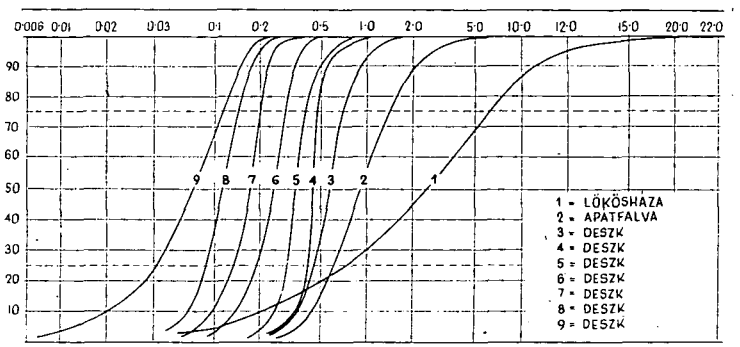


Fig. 2. Granulometric curves of the examined samples

2,5 mm. The coarsest sample (No *1*) is a gravelly coarse sand; the prevalent fraction of its grains is between 1,0 and 10,0 mm. That of Samples *2* and *3* is between 0,5 and 2,0 mm (Sample *3* being characterized by the same); consequently, both are coarse sands. In Samples *4* to *6* the medium grains, 0,2 to 0,5 mm ∅, are predominant.

Samples *7* and *8* are constituted by small sand (0,1 to 0,2 mm), whereas Sample *9* is a fine sand including a maximum of 40% of grains finer than 0,2 mm. All the analysed sands but the coarsest sample are well-sorted.

The nine samples comprise all grain fractions which may potentially be encountered in a heavy mineral study. A sediment coarser than the above does, in fact, rarely contain a grain fraction analysable with a mineralogical microscope and may abound in rock fragments. On the other hand, it is but in case of emergency, in absence of a coarser sediment in the formation, that a sediment finer than Sample *9* must be analysed. The results of such an analysis, however, do not stend up suit to closer scrutiny.

TABLE I.

Granulometric analyses of the examined samples

Number	Percentages of the different fractions (mm ∅)						*Md* in mm	*So*
	< 0,06	0,06—0,1	0,1—0,2	0,2—0,5	0,5—2,0	2,0 <		
1 (Lökösháza)	3,0	2,0	5,0	10,0	25,0	55,0	2,5	2,92
2 (Apátfalva)	0,0	0,0	0,0	15,0	74,0	11,0	0,92	1,55
3 (Deszk)	0,0	0,0	0,0	35,0	65,0	0,0	0,59	1,24
4 (Deszk)	0,0	0,0	0,0	83,0	17,0	0,0	0,45	1,08
5 (Deszk)	0,0	0,0	4,0	86,0	10,0	0,0	0,34	1,16
6 (Deszk)	0,0	3,0	26,0	71,0	0,0	0,0	0,25	1,23
7 (Deszk)	2,0	10,0	58,0	30,0	0,0	0,0	0,18	1,24
8 (Deszk)	7,0	30,0	58,0	5,0	0,0	0,0	0,12	1,28
9 (Deszk)	40,0	27,0	32,0	1,0	0,0	0,0	0,073	1,73

TABLE II.

Heavy mineral content of the samples

	Locality	Fraction in mm	Dominantly Magmatic Minerals										Dominantly Metamorphic Minerals								Other Minerals			Median diameter (*Md*) in mm
			Hypersthene	Other Ortho-Rhombic Pyroxenes	Augite	Diopside	Basaltic Hornblende	Magnetite Ilmenite	Biotite	Apatite	Titanite	Zircon	Chlorite	Turmaline	Zoisite	Rutile	Hornblende	Actinolite-Tremolite	Garnet	Staurolite	Kyanite	Calcite-Dolomite	Limonite	Weathered Minerals	
1.	1 (Lökösháza)	0,06—0,1	12,9	2,2	18,3	2,2	6,7	25,0	1,8	1,3	1,3	0,5	7,6	0,5	—	—	6,7	—	7,6	0,5	—	—	1,3	3,6	2,5
2.		0,1 —0,2	18,2	0,9	14,1	0,3	4,6	20,0	2,8	0,9	0,9	0,3	9,8	—	0,3	0,6	5,5	0,6	10,7	0,6	0,3	—	0,3	8,3	
3.		0,2 —0,32	12,1	0,4	18,5	1,9	2,3	15,4	1,5	0,4	—	—	12,5	—	—	—	6,8	0,4	7,6	1,1	2,3	0,8	0,8	15,2	
4.		0,32—0,63	11,2	—	18,6	1,2	2,3	17,1	1,9	—	—	—	10,1	0,4	—	—	1,9	—	11,2	0,4	0,4	1,6	—	21,7	
5.	2 (Apátfalva)	0,1 —0,2	16,2	2,3	14,8	1,6	5,2	15,7	1,3	1,6	0,3	—	7,2	—	—	—	9,2	0,3	14,1	—	0,3	3,0	0,3	6,6	0,92
6.		0,2 —0,32	15,9	1,2	18,9	0,4	3,7	12,2	0,4	1,2	—	—	5,7	—	—	—	5,7	—	16,3	—	1,6	2,9	0,4	13,5	
7.		0,32—0,63	6,9	0,5	11,2	—	0,5	16,5	3,2	—	—	—	30,9	—	—	—	2,1	—	9,6	—	1,1	0,5	—	17,0	
8.	3 (Deszk)	0,06—0,1	9,3	4,3	10,9	4,3	5,4	20,5	0,8	2,7	0,8	—	1,6	—	1,2	1,2	8,2	—	21,0	0,4	0,4	1,2	0,8	5,0	0,59
9.		0,1 —0,2	9,8	2,3	22,7	2,7	6,4	12,8	0,4	1,1	0,8	—	9,8	0,8	0,4	—	11,4	—	5,3	0,4	0,4	0,4	0,4	11,7	
10.		0,2 —0,32	19,8	1,3	26,3	0,9	5,2	10,8	1,3	0,4	—	—	4,3	—	0,4	0,4	2,2	0,4	18,5	0,9	—	0,4	0,9	5,6	
11.		0,32—0,63	8,6	—	16,7	—	2,7	22,6	2,7	—	—	—	17,7	0,5	—	—	3,8	—	2,7	—	1,6	—	—	20,4	
12.	4 (Deszk)	0,06—0,1	12,9	3,7	10,2	4,1	3,4	22,9	1,4	3,1	0,7	—	0,7	0,7	0,3	0,7	7,1	2,0	18,0	0,3	—	0,3	1,4	6,1	0,45
13.		0,1 —0,2	17,8	1,5	15,2	1,9	4,5	15,1	3,4	0,4	—	—	4,9	0,8	0,4	0,4	10,2	0,8	13,6	0,4	0,8	—	—	7,9	
14.		0,2 —0,32	18,8	3,0	24,0	1,7	3,0	10,9	—	0,4	—	—	3,0	—	0,4	0,4	8,3	—	8,3	0,4	0,4	0,4	0,4	16,2	
15.		0,32—0,63	2,7	1,4	12,9	0,7	1,4	25,2	2,0	—	—	—	19,7	—	—	—	2,0	—	—	—	0,7	—	2,7	28,6	
16.	5 (Deszk)	0,06—0,1	11,4	2,6	14,3	4,8	4,0	26,5	4,4	0,7	0,7	—	5,5	0,4	1,1	—	7,0	0,7	8,5	—	—	1,5	1,5	4,4	0,34
17.		0,1 —0,2	11,2	2,1	21,3	3,8	9'6	13,3	1,7	0,8	0,4	—	7,5	0,4	0,8	—	5,8	1,3	4,6	0,4	—	1,3	0,8	12,9	
18.		0,2 —0,32	7,7	—	9,8	0,5	3,6	19,2	7,2	0,5	—	—	12,4	—	—	—	6,2	1,0	1,0	—	1,5	1,0	0,5	27,9	
19.		0,32—0,63	6,1	—	6,1	1,7	0,9	24,3	13,9	—	—	—	20,8	0,9	—	—	3,5	—	0,9	—	0,9	0,9	—	19,1	
20.	6 (Deszk)	0,06—0,1	14,8	2,3	11,7	3,4	6,8	18,5	1,1	1,5	2,3	0,8	2,7	1,5	1,1	0,4	9,1	0,8	15,9	—	0,8	1,5	1,1	1,9	0,25
21.		0,1 —0,2	15,2	1,9	21,3	1,9	8,8	11,5	0,8	1,9	0,4	—	5,7	—	0,4	0,4	7,6	2,3	5,7	1,2	0,8	1,9	0,4	9,9	
22.		0,2 —0,32	5,0	3,0	21,2	1,0	7,5	12,6	7,0	0,5	0,5	—	6,5	1,0	—	—	7,0	1,0	1,5	—	—	2,5	1,5	20,7	
23.		0,32—0,63	6,3	2,4	10,1	—	4,8	12,6	10,6	0,5	—	—	14,5	0,5	—	—	8,7	—	2,4	—	0,5	0,5	2,4	23,2	
24.	7 (Deszk)	0,06—0,1	12,1	3,3	15,2	4,2	5,1	16,2	0,5	2,8	0,5	—	0,5	1,4	0,9	0,5	7,4	1,9	15,3	0,5	—	0,5	2,8	8,4	0,18
25.		0,1 —0,2	10,1	1,6	17,0	3,6	11,7	8,9	3,2	1,6	0,8	—	8,5	0,4	—	—	9,3	2,4	2,8	0,4	0,4	1,2	0,8	15,3	
26.		0,2 —0,32	2,9	0,4	7,8	0,8	4,5	14,3	11,1	—	—	—	15,2	—	—	0,4	6,1	0,4	0,4	—	—	0,4	2,0	33,3	
27.		0,32—0,63	1,6	—	3,1	1,6	1,6	7,8	32,8	—	—	—	42,1	—	—	—	3,9	0,8	0,8	—	—	—	—	3,9	
28.	8 (Deszk)	0,06—0,1	9,3	4,0	20,8	4,4	3,5	16,7	4,0	2,6	2,2	—	2,2	0,9	1,3	1,3	5,7	1,3	11,0	—	0,4	1,8	1,8	4,8	0,12
29.		0,1 —0,2	11,2	2,4	14,7	2,8	9,7	14,4	3,2	0,8	0,8	—	5,6	0,4	0,4	0,4	11,2	2,0	6,0	—	0,4	2,4	0,8	10,4	
30.		0,2 —0,32	4,5	0,5	4,5	0,5	4,5	20,7	31,3	0,5	—	—	23,0	—	—	—	2,8	1,7	—	—	—	0,5	—	5,0	
31.		0,32—0,63	1,4	—	—	—	4,1	4,1	62,1	—	—	—	21,5	—	—	—	6,8	—	—	—	—	—	—	—	
32.	9 (Deszk)	0,06—0,1	12,7	2,5	16,6	0,5	6,4	16,2	2,9	3,4	2,9	—	2,5	0,5	—	1,5	5,4	1,0	12,7	0,5	1,0	1,0	2,0	7,8	0,073
33.		0,1 —0,2	11,0	1,8	13,9	2,2	10,1	13,1	4,4	0,9	0,4	—	7,5	0,9	0,4	—	8,8	1,3	6,1	—	0,4	1,8	1,8	13,2	
34.		0,2 —0,32	0,5	—	5,9	0,5	4,5	17,6	30,2	—	0,5	—	25,7	—	—	—	7,2	0,9	0,5	—	0,5	0,5	0,5	4,5	
35.		0,32—0,63	—	—	1,9	—	—	7,5	66,1	—	—	—	13,2	—	—	—	3,8	—	—	—	—	—	—	7,5	

The selected fractions were separated in bromoform into minerals of a specific gravity higher than 2,88 and into one of a lower specific gravity. The separated heavy minerals were put on an object plate and studied under a mineralogical microscope.

According to W. A. P. GRAHAM, [1930], in a heavy mineral analysis it is enough to determine 100 grains to obtain satisfactory result. This statement is wrong, as at least 150 grains have to be examined, as found earlier by the author [B. MOLNÁR, 1959], in order that the question of origin may be answered. The determination of 100 grains may prove sufficient in the case when only a few species of heavy minerals are present in the sample. Should this be the case, so even the determination of fewer grains will give correct values as to the percentage distribution of the mineral grains. W. A. P. GRAHAM, [1930] too found a total of nine mineral species in the sample examined.

According to A. L. DRYDEN, [1931] the accuracy of the results will increase with the square root of the number of grains counted. This author has stated, however, that potential errors will markedly decrease, if the number of counted grains is higher than 300. Therefore, the author determined nearly 300 grains in his own studies.

Another requirement is to examine at least two size fractions of the sample when heavy minerals are considered. W. W. RUBEY, [1933] has suggested to keep one of the two constant in all of the samples and to select the other fraction so that it may have the same relative position within the total size range (e. g. smaller than the median) in all samples.

The resultant values of the heavy minerals indicate the rations of the mineral grains counted. In other words, the percentage frequencies of the minerals, rather than their volume or weight percentage composition, will be obtained. *Nota bene,* there is a difference in the specific gravity of the individual minerals; (for instance, it is only as to the number of occurrence that the same percentage of two minerals of different specific gravity in the sample agree with each other).

The actual heavy mineral content of Maros River sands, i. e. the gravity of the heavy minerals as compared to the rest of the minerals, is already known from earlier studies: 1 to 5% in dependence on the grain composition. If considered in one and the same sample, this figure increases from the coarser fractions towards the finer ones, varying between 1 and 20% [J. MEZŐSI and E. DONÁTH, 1951; B. MOLNÁR 1963, 1964/a, 1964/b, 1965/a, 1965/b, 1966, 1968].

However, this is not necessarily true for all types of sediment. G. WOLETZ, [1958] discussed a sand in which the heavy minerals exhibit the highest abundance in a fraction other than the finest.

With the exception of Sample 2 — in which the 0,06 to 0,1 mm fraction was absent — the heavy mineral composition of four fractions (still examinable under the mineralogical microscope) were examined in each sample on the basis of the determination of nearly 300 grains, as mentioned above (Table II). The maximum of the mineral species identified was 21. Because of the knowledge of the lithological composition of the source area, the minerals could be classed according to their source, too. Out of the 21 minerals, the number of minerals of more than 5% ratio was as low as 7. The unidentifiable, altered,

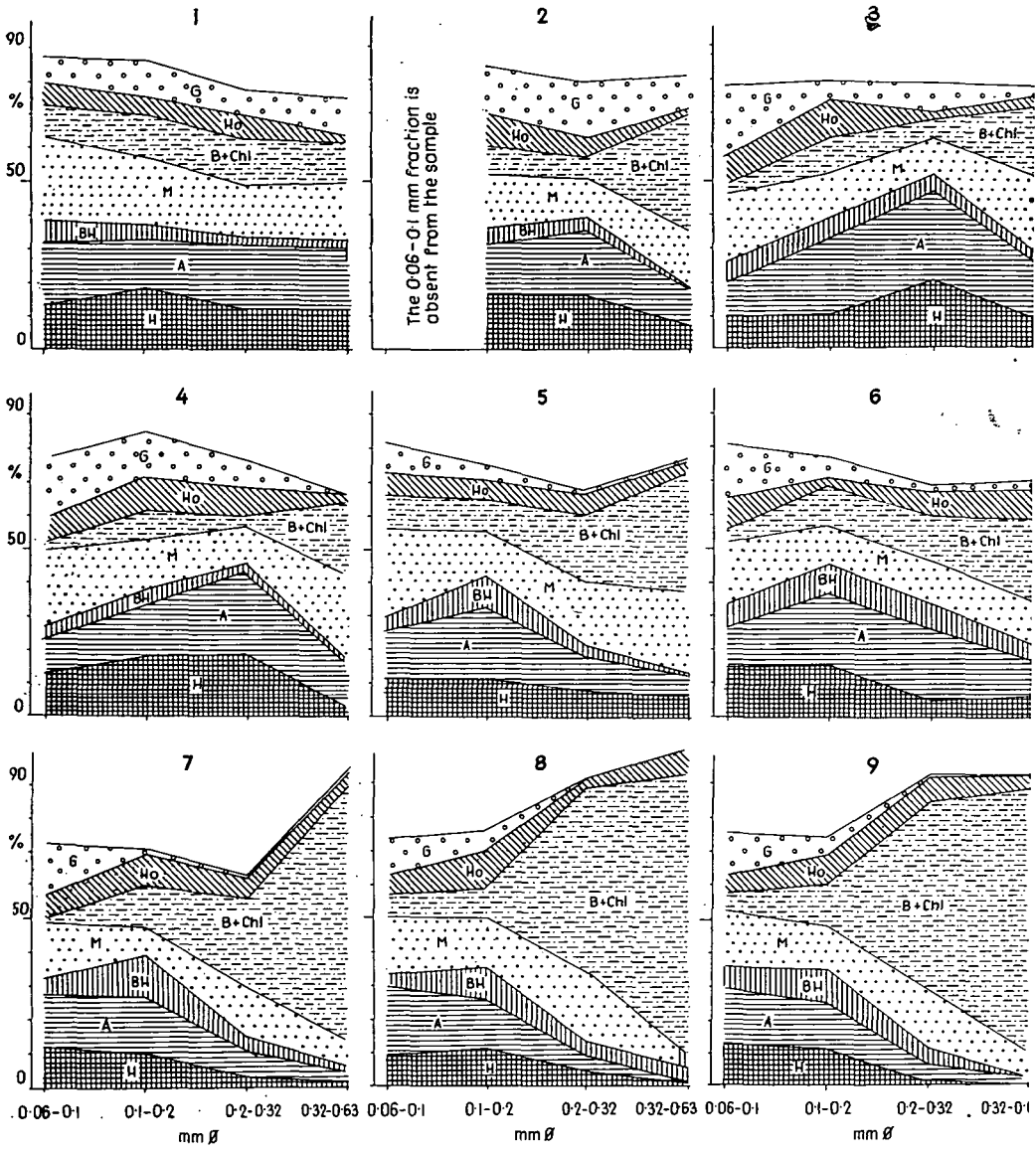


Fig. 3. Percentage distribution of heavy minerals predominant in the various fractions of Samples *1* to *9*

H: Hypersthene
A: Augite
BH: Basaltic Hornblende
M: Magnetite
B + Chl: Biotite + Chlorite
Ho: Hornblende
G: Garnet

minerals were, of course, disregarded during the determination of the origin.

1) The quantitative distribution of the 7 most important heavy minerals by samples and fractions is shown in *Fig. 3.* In Sample *1,* representing a sediment of coarsest grain composition, it is evident that the 7 minerals show the same percentage ratio in the various fractions. In Samples *2* to *6,* representing coarse to medium sands, there are, however, marked fluctuations in the correlative percentage rations of the same minerals in the various fractions. Magnetite and garnet rise slightly above the average as compared to the samples of finer grain composition. In Samples *7* to *9* (fine to finest sands)

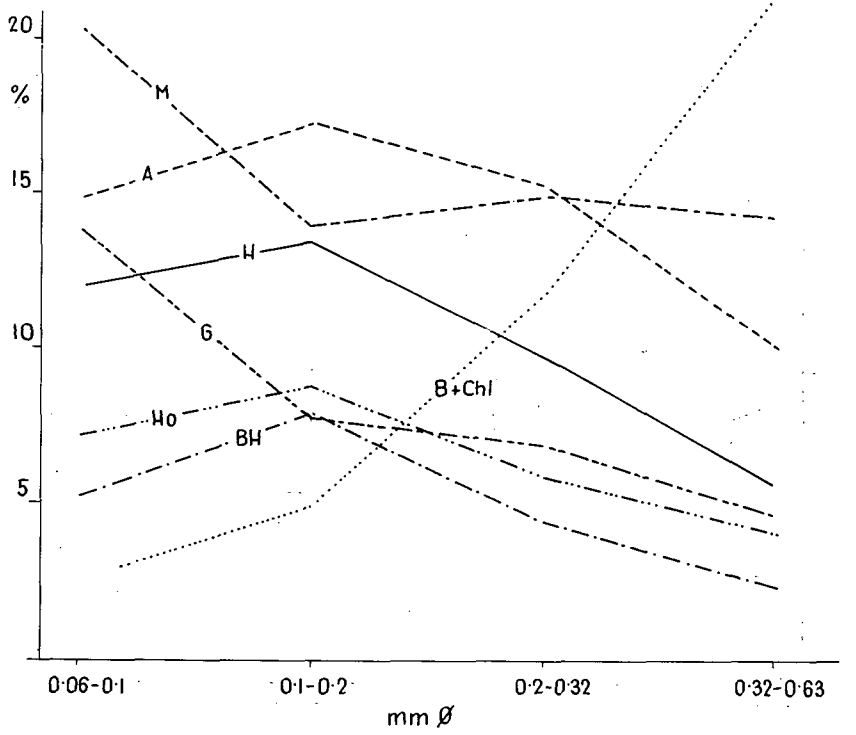


Fig. 4. Percentage values of heavy mineral averages as found in the various fractions of Samples *1* to *9* (for legend, see Fig. *3*)

these differences become further accentuated. The coarser fractions of these samples have a composition other than the finer fractions have. The difference is due, in the first place, to the high percentage of biotite and chlorite.

Hence, whichever fraction of a coarse sand should be examined, the results will be the same; in case of medium sands they are still acceptable, but the finer fractions of both coarse and medium sands are characterized by a slight rise of the abundance of magnetite and particularly of garnet, exceeding the average. In case of small and fine sands, it is only the 0,06 to 0,2 mm fractions that yield evaluable results.

2) Fig. 4 shows the average values of the 7 most frequent minerals, as counted in the various fractions of the nine examined samples. Proceeding

from the finer fractions towards the coarser ones, one can see a break in the average of every mineral at the 0,1 to 0,2 mm fraction. The average of magnetite and garnet shows a strong increase as compared to the average of the rest of the minerals in the finer fractions. In fractions coarser than 0,1 to 0,2 mm, magnetite does not exhibit any essential change, the averages of the other minerals diminish, while mica is multiplied: in the 0,2 to 0,32 mm fraction it is close to 12% (in contrast wit the 5% found in the previous fraction), to become as high as 22% in the 0,32 to 0,63 mm fraction.

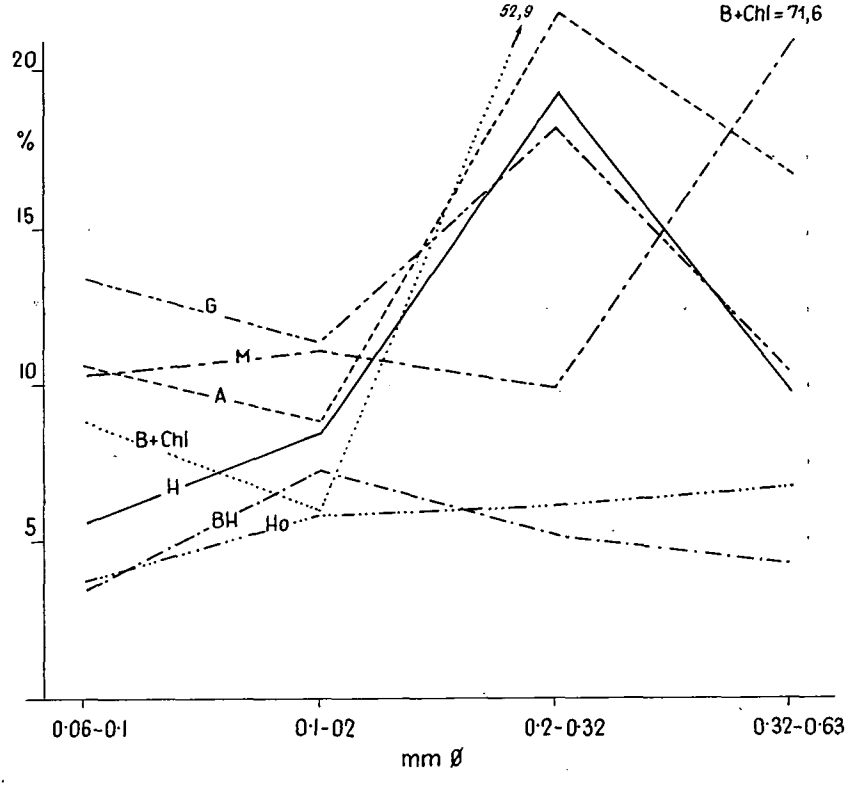


Fig. 5. Divergences between the lowest and the highest percentage abundances of the heavy mineral grains abundant in the various fractions of Samples *1* to *9* (for legend, see Fig. *3*)

3) Fig. 5 illustrates the differences of the frequencies of the same 7 minerals, as reflected by the contrast between the smallest and the largest mineral percentage in the different fractions and mineral types. For instance, the lowest hypersthene percentage of the 0,06 to 0,1 mm fraction is in Sample *8* (9,3%), the highest (14,8) in Sample *6*; hence, the difference between the two equals 5,5%.

These differences are not insignificant in the 0,06 to 0,1 and 0,1 to 0,2 mm fractions, either; but here they may remain subconstant for particular minerals. The higher the percentage of a mineral (in terms of grain number) in the various samples, the more striking the difference between the extreme values

of occurrence. For instance, hypersthene is present in all samples and in most of the fractions in a higher percentage than this is the case with basaltic hornblende; hence, the divergence between the highest and lowest percentage values of the hypersthene grains is also higher, even as distributed among the various fractions, than that of basaltic hornblende.

From the fraction 0,2 to 0,32 mm towards the coarser fractions, however, the divergence of extreme values will show a sudden increase and become rather unsteady for the minerals other than basaltic hornblende, hornblende and a part of magnetite. Out of the rest of the minerals it is biotite and chlorite that is prominent, being characterized by a particularly marked increase of abundance: to above 71% in the 0,32 to 0,63 mm fraction as contrasted against the figure as low as 6% in the 0,1 to 0,2 mm fraction and as high as 53% in the 0,2 to 0,32 mm fraction. Consequently, it is only one of the finer fractions that can come into consideration in heavy mineral analyses.

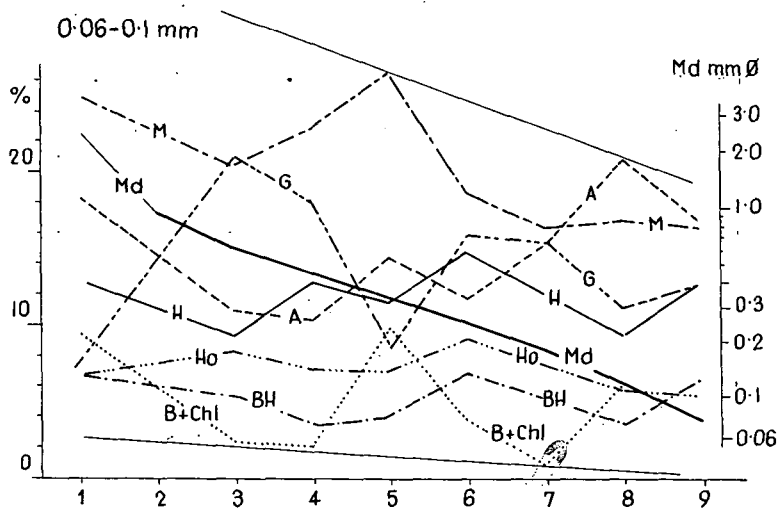


Fig. 6. Percentage abundances of predominant heavy mineral types in the 0,06 to 0,1 mm fractions of the examined samples (for legend, see Fig. *3*)

4) The minor minerals may in many a case be very important for the determination of the mineralogical composition of the sediment, as they may serve as indicators of certain characteristics geological features. During the present study these minerals were found to be mainly confined to the finer fractions (Table II), though occasionally they were absent even here, a fact due to the lower frequency of their occurrence. In the coarser fractions they were totally absent in most cases.

The abundance of altered minerals is often dependent on dia- and epigenetic processes, providing no information as to the proper origin of the sediment. In case of the correlation of two sequences, however, it may prove a useful tool for strata identification, if there are layers differing altered mineralization from the rest of the sequence.

Accordingly, in the first 6 samples (Samples *1* to *6*) examined, i. e. in coarse and medium sands, the amount of altered minerals usually increases

from the finer towards the coarser fractions. In small and fine sands (Samples *7* and *8*) the examined finest and coarsest fractions are characterized by a lower, the intermediate fractions by a higher, abundance of altered minerals.

Consequently, the results hitherto presented testify that the actual heavy minerals composition of the individual samples can be approximated in the case, when one of the finer fractions of the sample is examined.

5) Figs. 6 to *8* indicate the variation of the heavy mineral conent of a single fraction of each analysed sample. In the following discussion the percentage occurrence of grains of the predominant heavy mineral species in single fractions of samples of different grain composition will be considered. *Nota bene*, what is commonly of interest is not the heavy minerals composition of an individual sample, but to find out – by analysing one and the same fraction of several samples by the aid of serial analysis – wether the results to be obtained in case of identical origin are the same or (should the origin happen to be doubtful) the data can be intercorrelated.

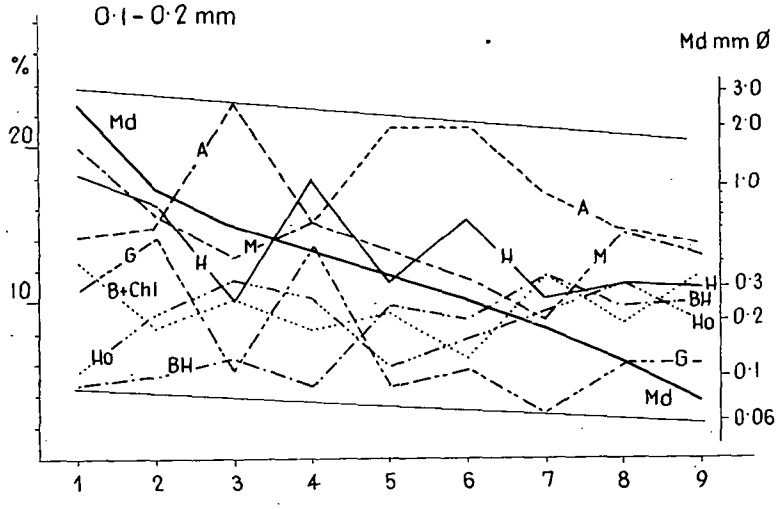


Fig. 7. Percentage abundances of predominant heavy mineral types in the 0,1 to 0,2 mm fractions of the examined samples (for legend, see Fig. *3*)

Fig. 6 shows the percentage distribution of the heavy mineral grains predominating in the 0,06 to 0,1 mm fraction of the 9 samples as well as the median diameter values obtained for the individual samples *(Md)*. The area of the percentage plots of mineral grains has been delimited by two straight lines. These are divergent towards the coarser fractions, touching the magnetite and augite curves at the top and the garnet curve at the bottom.

On *Fig 7* the percentage distribution of the heavy mineral grains of the 0,1 to 0,2 mm fraction has been represented in the same way. Here the two tangent lines are subparallel, embracing a belt substantially narrower than in the former fraction. This means that in this fraction the fluctuations of the indvidual mineral percentages are less marked. The slight growth of area observed towards the coarser samples is an evidence of the increasing abundance of the predominant minerals.

In *Fig. 8* the percentage occurrences of heavy mineral grains in the grain size range of 0,2 to 0,32 mm have been represented. The tangent straight lines here converge towards the finer samples (in contrast with the fraction of 0,06 to 0,1 mm), delimiting a considerably larger area than those shown in the previous figures, a fact due to fluctuations in the abundances of the predominant minerals.

Thus, the values of the coarsest fraction, 0,32 to 0,63 mm, could not be represented. It should be noted that in this fraction even the 7 predominant minerals were not fully represented in many cases. Therefore this fraction cannot come into consideration.

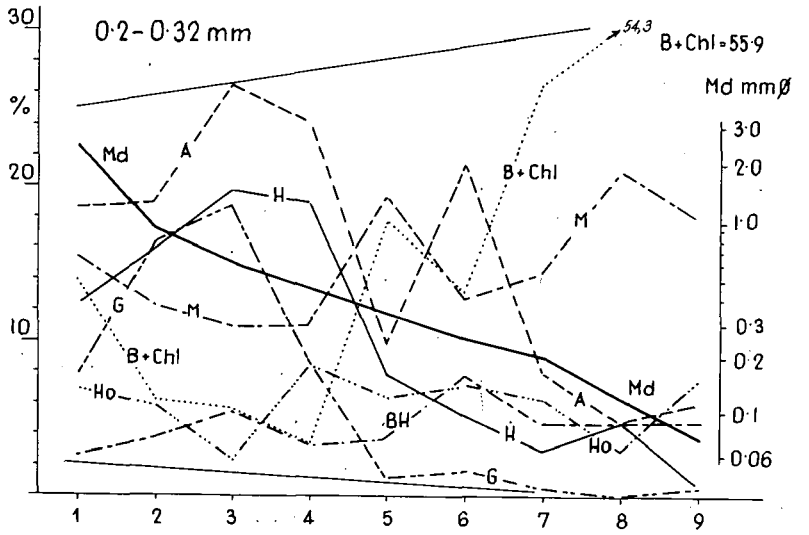


Fig. 8. Percentage abundances of predominant heavy mineral types in the 0,2 to 0,32 mm fractions of the examined samples (for legend, see Fig. *3*)

CONCLUSIONS

As suggested by a comparison of Samples *6* to *8*, finer fractions are characterized by a divergence of the percentage of mineral grains towards the coarser samples, the coarser fractions are so towards the finer samples when the heavy mineral composition of sediments of different grain composition are examined. The intermediary, 0,1 to 0,2 mm, fraction yields the most favourable averages. The peak of garnet and magnetite, observable in the finer fractions, (0,06 to 0,1 mm) cannot yet be observed here. On the other hand, the increase of the abundance of mica, characteristic of the coarser fractions, cannot be observed, either.

It can be stated that the results obtained for the 0,1 to 0,2 mm fraction of samples of different grain sizes are readily comparable with one another and that the problem of source of the sediment can be settled on the basis of these data.

The results of the present study are in complete agreement, with respect to magnetite, with those calculated theoretically by W. RUBEY, [1933]. Here too, the abundance of magnetite showed an increase towards the finer fractions. The enrichment of mica in the coarsed fractions is also due to deposition in the liquid. Having a very large surface as compared to their specific gravities, the mica grains remain suspended for a long time and are more easily kept in motion by the river. This is the reason why they will settle with the coarser sand fraction.

In contrast with the results of L. HAWKES and A. J. SMYTHE, [1931], the abundance of garnet showed an increase towards the finer fractions and such an increase has been common for all the Hungarian results of heavy mineral analyses. Beside the fairly high specific gravity (3,5—4,5), this phenomenon is also connected with the resistance to weathering of the garnet grains.

Consequently, the results of heavy minerals determinations can be best correlated when the predominant grain diameter of the examined sediment is within the 0,15 to 0,25 mm range. Grain composition implies some limitation to the method. Therefore, it is not advisable to use it mechanically. For instance, it would be unreasonable to analyse and correlate, in a sedimentary sequence, every fine-grained sample containing the 0,1 to 0,2 mm fraction in a few per cent only.

Should the method be used under such conditions, so e. g. the coarser, transgressive member of a sedimentary sequence would show a completely different composition than the later deposited, finer-grained member, even if the source area did not change in the meantime. Hence, the only solution is to select layers of subequal grain diameter for analysis. If this is impossible and if there is little difference in grain composition among the samples (e. g. fine-grained and medium-grained sands), one has first to scrutinize the percentage variation of the minerals present. Conclusions can be drawn after this has been done. However, it is by no means reasonable to compare the composition of a differently grained sediment — the less so a fine-grained one (slightly sandy silt) — with the composition of a coarse sand or of a sediment of even coarser fraction; nor is so to infer any actual difference therefrom.

SUMMARY

If the heavy minerals composition of a coarse-grained material with a median of $>$ 0,5 mm is examined, any of its grain-size fractions will yield results corresponding exactly to the composition of the entire sample. Although medium sands (0,2 to 0,5 mm) exhibit some slight fluctuation of mineral percentages in the various size fractions, the values are acceptable. In case of small to fine sands (predominant grain diameter: from 0,06 to 0,2 mm), however, it is merely the fractions of the 0,06 to 0,2 mm range that yield evaluable data.

Should a sediment comprising a wide range of grain size from fine sand to granules, be analysed for heavy minerals, the results cannot be compared with one another unless the fractions of the 0,06 to 0,2 mm range are considered.

REFERENCES

DRYDEN, A. L. [1931]: Accuracy in Percentage Representation of Heavy Mineral Frequencies. Proc. Nat. Acad. Sci., *17*, 233—238.

GRAHAM, W. A. P. [1930]: A Textural and Petrographic Study of the Cambrian Sandstones of Minnesota. Jour. Geology *38*, 696—716.

HAWKES, L., SMYTHE, A. J. [1931]: Garnet—Bearing Sands of the Northumberland Coast. Geol. Magazine, *68*, 345—361.

HSU, K. J. [1960]: Texture and Mineralogy of the Recent Sands of the Gulf Coast. Journ. of Sedimentary Petr., *30*, 3, 380—403.

KODYMOVA, A. [1966]: Težké minerály v nápalaveck českýok řek. Sbornik Geologických VĚD. řăda G. sv. *11*, 115—133.

MCMASTER, R. L. [1962]: Petrography and Genesis of Recent: Sediments in Narraganselt Bay and Rhode Islands Sound, Rhode Island. Journ. of Sedimentary Petr., *32*, 3, 484—501.

MEZŐSI, J., DONÁTH, É. [1951]: The Mineralogical and Chemical Investigation of the Floating Material of the Maros and Tisza. Acta Miner. Petr., Acta Univ. Szegediensis T., *5*, 38—57.

MIRSKY, A. [1961]: Mechanical Analysis and Heavy Minerals, Morrison and Cloverly Formations, Southern Big Horn Mountains, Wyoming Journ. Sed. Petr., *31*, 3, 571—558.

MOLNÁR, B. [1959]: A statisztikus nehézásvány-vizsgálat hibalehetősége (Fehlermöglichkeiten der statistischen Schwermineral-Analyse). Földtani Közl., *89*, 3, 294—297.

MOLNÁR, B. [1963]: Untersuchung über den Zusammenhang der Sandkorngrösse und der Schwermineralzusammensetzung. Acta Miner. Petr., Acta Univ. Szegediensis T., *16*, 1, 25—33.

MOLNÁR, B. [1964/a]: On the Relationship between the Lithology of the Abrasion Area and the Transported Sediments. Acta Miner. Petr., Acta Univ. Szegediensis T., *16*, 2, 69—87.

MOLNÁR, B. [1964/b]: A magyarországi folyók homoküledékeinek nehézásvány-összetétel vizsgálata (Untersuchungen der Schwermineralien—Zusammensetzung der Sandablagerungen der Flüsse Ungarns). Hidrológiai Közlöny *44*, 8, 347—355.

MOLNÁR, B. [1965/a]: Lithologic and Geologic Study of the Quaternary Deposits of the Great Hungarian Plain (Alföld). Acta Geologica Hungarica *9*, 57—63.

MOLNÁR, B. [1965/b]: Ősvízrajzi vizsgálatok a Dél-Tiszántúlon (Geohydrological Investigations in South-East Hungary). Hidrológiai Közl., *45*, 9, 397—404.

MOLNÁR, B. [1966]: Lehordási területek és irányok változásai a Dél-Tiszántúlon a pliocénben és pleisztocénben (Änderungen der Abtragungsgebiete und -richtungen im Süd-Tiszántúl im Pliozän und Pleistozän). Hidrológiai Közlöny *46*, 3, 121—127.

MOLNÁR, B. [1968]: Sedimentationszyklen in den pleisztozänen Ablagerungen des Südlichen Ungarischen Beckens. Geologische Rundschau *57*, 2. Stuttgart, 532—557.

RUBEY, W. W. [1933]: The Size-distribution of Heavy Minerals within a Water-laid Sandstone. Journal of Sedimentary Petrology *5*, 3, 3—29.

SHEPARD, F. P., MOORE, D. G. [1960]: Bays of Central Texas Coast. The Am. Ass. of Petroleum Geol., *44*, 118—152.

SHEPARD, F. P. [1960]: Mississippi Delta: Marginal Environments, Sediments, and Growth The Am. Ass. of Petroleum Geol., *44*, 56—81.

WENDL, A. [1954]: Geológia I. Tankönyvkiadó. Budapest, 277.

VAN ANDEL, T. H. [1964/a]: Vector Analysis of Heavy-mineral Data. Geol. Society of. Am. Bull., *75*, 1131—1156.

VAN ANDEL, T. H. [1964/b]: Recent Marine Sediments of Gulf of California. The Am. Ass. of Petroleum Geol., *48*, 216—310.

WOLETZ, G. [1958]: Die Schwermineral-Analyse als Hilfsmittel für Prospektion und Stratigraphie. Verhandlungen der Geologischen Bundesanstalt Wien *98*, 2, 172—182.

DR. BÉLA MOLNÁR,
Institute of Geology
Attila József University at Szeged
Táncsics M. u. 2.
Szeged, Hungary

EXAMINATION OF OVERPRESSURE RESERVOIRS IN THE SOUTHERN GREAT HUNGARIAN PLAIN: A CLASSIFICATION OF THE CAUSES OF OVERPRESSURE

A. SOMFAI

INTRODUCTION

The experience of drilling oil- and gas-wells, the spectacular oil- and gas-blowouts of recent years as well as the pressures measured during formation-testing have proved convincingly that the pressure of reservoir fluids is higher than the hydrostatic pressure. The knowledge of *„reservoir pressure"* is important for designing optimum drilling mud technology, casing program and well completion, for calculating the oil-and-gas reserves as well as for the design of optimum exploitation, etc. If reservoir pressure can be characterized by overpressure, which is though not the general rule, but which occurs more and more frequently with the spread of deep and super-deep drilling, then its recognition and eventual forecasting are of very great significance (beside the above considerations) for preventing any upset of borehole equilibrium. This will certainly have substantial economic effect, being necessary for safe well-drilling.

During wildcatting in unknown structures one has to know the causes responsible for the development of overpressures and the results of preliminary geophysical and geological exploration of the area.

In the present paper the author seeks to make use of his experiences, both direct and indirect, in connection with the overpressure reservoirs of the southern Great Hungarian Plain and the laboratory analyses of rock and fluid samples from the territory, in order to summarize the theories which are to be taken into account under the conditions existing in Hungary.

The tests and conclusions as well as the basic information utilized refer primarily to the Algyő deposit. However, they can be extended to a number of Hungarian compaction structures as well.

GEOLOGICAL SETTING

The *"core"* of the compaction structures under consideration is formed by a relative elevation of the pre-Tertiary basement. This is made up of Paleozoic (metamorphic schists, granites, quartz porphyry, etc.) or Mezozoic rocks (marl-shale, limestone, dolomite, etc.), as a rule, heavily affected by tectonic deformation or of intensively folded Upper Cretaceous to Paleogene flyschoidal

sediments (marls, clay-marls, sandstones, conglomerates, etc.). In many places — usually at the limbs of the structure — the basement is unconformably overlain by a Miocene sequence of varied lithology (sandstones, conglomerates, marls, tuffs, limestones, etc.) which fills up the deeper basin portions in a spotted or zonal pattern.

The Lower Pannonian sequence locally begins with a so-called "*basal conglomerate*" consisting of basement rocks and this is covered by calcareous marls usually a few metres, eventually several tens of metres thick. The sandstones of the next sequence consisting of clay-marls and sandstones are quantitatively subordinate (accounting for about 20% of the sequence). In fact, they are totally absent in some places (Szank, Ásotthalom). They are characterized by the lack of sorting, high clay content, usually low porosity and permeability, relative changes of facies grading into marls and by the lenticular occurrence of the sandstones. In the clay-marls illite predominates over montmorillonite. Since the finer-grained sediments are more liable to compaction than the coarser ones, the Lower Pannonian sediments show a more advanced stage of compaction and their adjusting to the morphology of the structure-forming basement "core" is — because of the predominant clay content and the higher pressure of the overburden — substantially more pronounced than it is the case with the Upper Pannonian sediments. Consequently, the dip of the strata of this structure shows a gradual upward decrease.

The Upper Pannonian sequence is constituted predominantly by a frequent alteration of sandstones, clay-marls and siltstones. In the Upper Pannonian the sand content is substantially higher and the so-called "*pure sandstones*", more sorted, poor in clay, rather porous and permeable, occur more frequently. The succession and connection of the sequence consisting of sandstones and clay-marls and their transitions are such as they do not form any hydrocarbon trap or reservoir structure of regional extension, as they pinch out within rather small distances and show an intricate pattern of intertonguing. Thus in respect of the comparatively large lenses, it cannot be found out whether it is the sandstones that form intercalations in clay-marls or vice versa? This conclusion is crucial for oil geology, as it means that — even though in the Upper Pannonian several reservoirs, separated from one another by impervious layers, can form a vertical succession within one structure and though the reservoirs may include such oil- and gas-pools which may be considered independent hydrodynamic units — these latter are nevertheless hydraulically interconnected in some intricate way and this hydraulical connection is traceable up to the surface. The Upper Pannonian beds too are adjusted to some extent to the morphology of the basement, though their curvature is smaller than that of the Lower Pannonian sediments. Their position is closer to the horizontal, for their compaction is also lower. The Quaternary sediments form a sequence of sandstones, clays and siltstones. These being of little significance from the point of view of oil- and gas accumulations, there is no use discussing them here in detail.

RESERVOIR PRESSURE

The fluids (water, oil, gas) are situated in the pores (possibly fissures or caverns) of the reservoir rock. To denote its pressure the term "*reservoir pressure*" has been proposed.

As regards such terms as *"bed pressure"* (referring just to the pressure of the hydrocarbon-bearing body) or *"formation pressure"* or *"strata pressure"* or even *"overburden pressure"*, etc., none of them does cover the notion more satisfactorily, for the notion of reservoir pressure can be extended to include the pressure value of any bed or formation occurring within the reservoir structure.

In the compaction structures of the southern Great Hungarian Plain the reservoir pressure is hydrostatic in the Upper Pannonian and Quaternary sediments which are in the state of *"pressure equilibrium"*.

Hydrostatic pressure means that the pressure of the reservoir being considered is equal to the pressure of water column corresponding to the vertical distance between the piezometric surface and the depth of the reservoir in pressure equilibrium. Consequently, the value of formation pressure results from the potential energy of the water-bearing sequence. The specific weight of the water column is defined by the average specific weight of the aquifers as calculated with regard to the temperature of the sedimentary sequence. In the Great Hungarian Plain the piezometric surface corresponds approximately to the surface of sediment.

Pressure gradient:

$$\frac{P\ (at)}{H\ (m)},$$

is the ratio of reservoir pressure to the depth of the reservoir (vertical distance between the rock surface or piezometric surface and the virtual (observed) position of the reservoir, i. e. the rise in pressure corresponding to 1 m depth increment.

In case of hydrostatic pressure the pressure gradient will vary between 0.1 and 0.108 atm/m in dependence on the density and temperature of water contained in the sedimentary sequence.

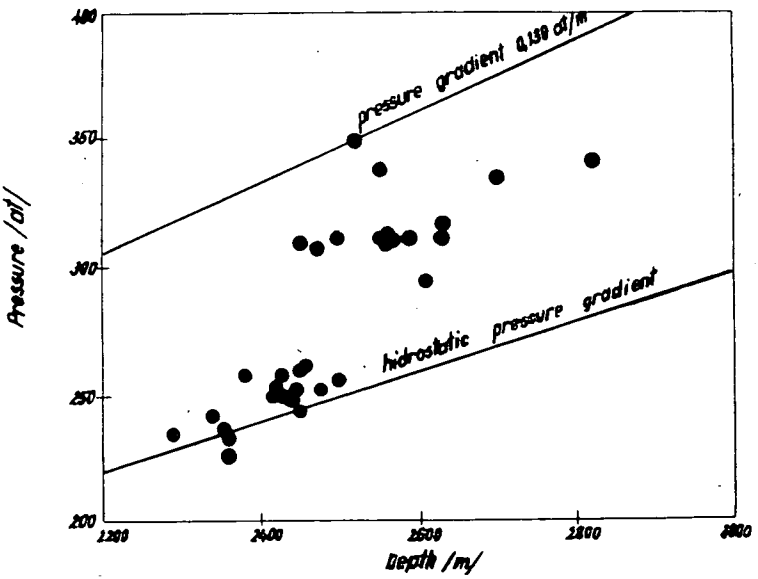


Fig. 1. Pressures measured in the Lower Pannonian sandstone reservoirs of Algyő, varying between the hydrostatic pressure and the pressure gradient 0.130 atm/m.

In some of the structures explored in the southern Great Hungarian Plain, in pre-Upper Pannonian Neogene sediments, pressure values differing from the hydrostatic pressure, i. e. a rise in the pressure gradient, can be measured. For instance, for the oil-water interface of the basal conglomerates at Algyő,

a pressure gradient of 0.124 atm/m was calculated, while the maximum obtained for the gas cap of the same bed was 0.130 atm/m. The Lower Pannonian sandstone reservoirs show a pressure gradient attaining a maximum of 0.110 to 0.115 atm/m. The measured pressures are shown in *Fig. 1.*

At Szank, the pressure gradient within a Miocene bed varies between 0.130 and 0.140 atm/m, whereas in the gas reservoir of the Tortonian conglome-

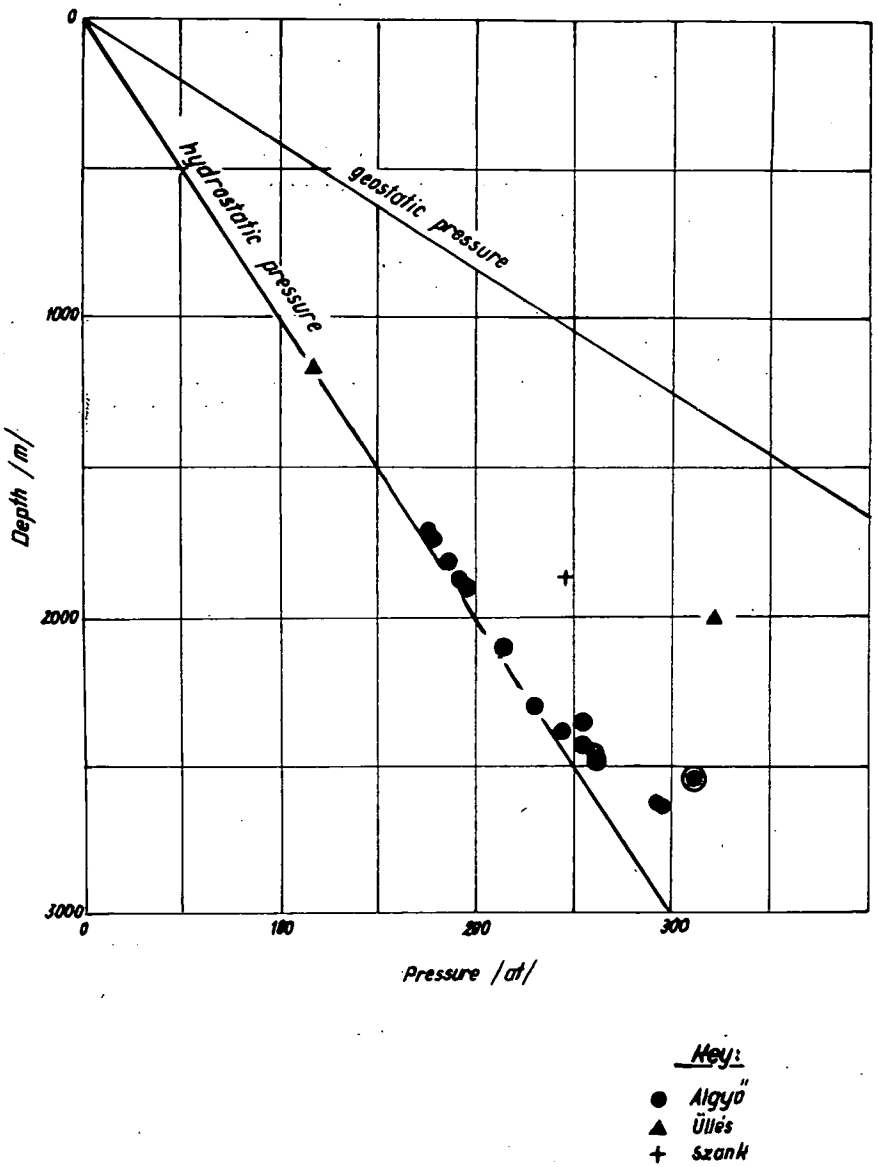


Fig. 2. Pressure versus depth of the overpressure reservoirs of Algyő, Üllés and Szank, southern Great Hungarian Plain, as compared with the hydrostatic and geostatic pressure gradients.

rates at Üllés, at 2,002 m depth, a formation pressure of 322 atm was measured, a value indicating the presence of a pressure gradient of 0.161 atm/m. In *Fig. 2* a few characteristic pressure values of the afore-mentioned areas are shown.

The figure shows a straight line corresponding to the hydrostatic pressure values and the line of the geostatic pressure gradient, indicating the overburden pressure values at particular depths.

(Geostatic pressure is also called overburden pressure or formation pressure. Its gradient equals about 0.23 atm/m.)

When the pressure of a reservoir exceeds the hydrostatic value, the reservoir is considered to have *overpressure*. Consequently, overpressure means that the pressure of the reservoir is higher than the pressure of the water column corresponding to the vertical distance between the land surface and the depth of the reservoir.

Overpressure is often given in terms of percentages, this being a value equalling thousandfold pressure gradient minus 100. For instance, at Üllés: $(0.161 \times 1000) - 100 = 61\%$.

None of the reservoir beds of the Algyő structure does show a fluid pressure lower than the hydrostatic value. Prospectors of hydrocarbons in Hungary encountered in a number of cases the so-called *"iszapveszteséges réteg"* (a bed characterized by significant losses of drilling mud) which can be easily confused with reservoirs referred to as *"of low pressure"* or *"of unsatisfactory pressure"*, *"of subnormal pressure"*, etc. In this connection the following observations should be made. On one hand, because of the fracturing, natural or artifical, of the reservoir, its caverned structure, low degree of consolidation or *"rough permeability"*, the rock may be liable to lose drilling mud even in case of hydrostatic reservoir pressure or possibly even at overpressure. On the other hand, not even the strata *"of unsatisfactory pressure"* must show mud losses.

Unsatisfactory pressure means that the pressure of the reservoir is lower than the pressure of the water column corresponding to the vertical distance between land surface and reservoir depth.

THE ORIGIN OF OVERPRESSURES AND DESCRIPTION OF THE RESERVOIRS

Of the overpressure reservoirs, first of all, the Lower Pannonian conglomerates are to be considered; it is they that show the highest pressure gradient and that contain a gas reservoir of great industrial value, bordered by a thin oil-bearing layer. The basal conglomerates consist of white-grey, unconsolidated quartz and metamorphite debris cemented by calcium carbonate, silt or sandstone particles. They rest immediately on a Paleozoic basement, fractured, heavily affected by tectonic strains. In *Fig. 3* the countour-map of the Paleozoic surface, in *Fig. 4* the map of the upper surface of the conglomerates are shown. Seemingly of transgressive origin, the conglomerates surround the basement high in a collarlike pattern, as illustrated by *Fig. 5* plotted axonometrically. As evident from the picture drawn with a vertical scale of fivefold exaggeration, the conglomerates vary in thickness and extend little, if any, below the 2,900 m depth limit. In the deeper horizons they thin and then pinch out. However, they do not extend above the 2,400 m subsurface level, either, being absent there too. Consequently, the Lower Pannonian basal conglomerates, lying between the impermeable basement and the hanging calcareous marls or clay-marls, represent a closed lens or, rather, ring which is isolated from the overlying Lower Pannonian sandstones. According

to present-day evidence, they are not interconnected with the Miocene rocks uncovered in the deeper limb portions, either. By the way, a connection of this kind would — as evidenced clearly by later parts of this paper — just widen the scope of the isolated system, and even though it would imply a common pressure system for the two formations, it would not modify the results presented here.

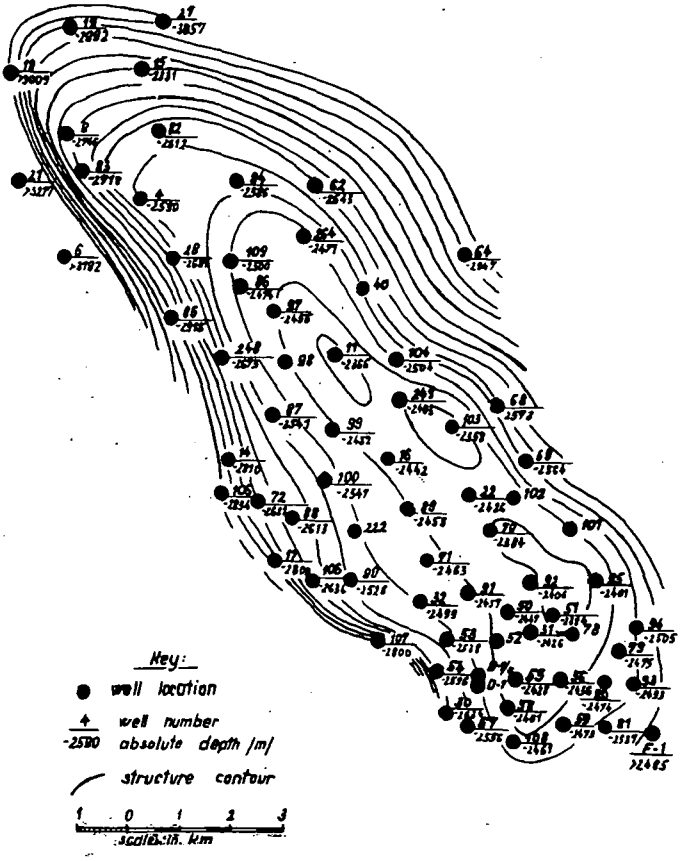


Fig. 3. Contour map of the surface of the Paleozoic basement of Algyő with indication of borehole locations.

Like the basal conglomerates, the Lower Pannonian sandstones of higher structural position can also be interpreted as such closed reservoirs which either grade into marls or pinch out within smaller or greater distances. In the Lower Pannonian some of the sandstone reservoirs can be shown convincingly (by data of drilling) to pinch out in certain direction still within the wild-cat area, while in the near-by Ásotthalom or Szank areas the Lower Pannonian does not include a single sandstone layer.

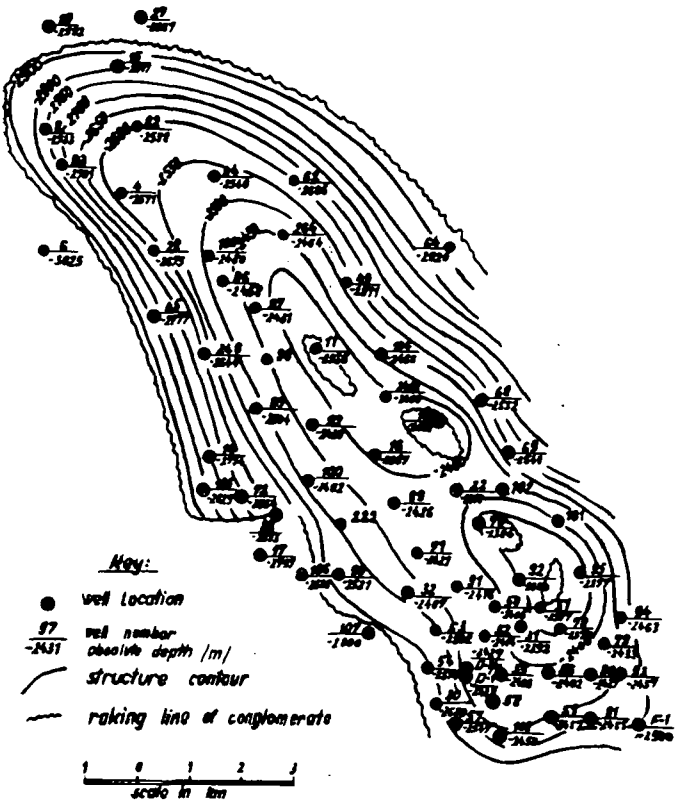


Fig. 4. Map of the upper surface of the Lower Pannonian basal conglomerates at Algyő. Wavy line indicates the limit of pinching out.

It can be stated unequivocally here that, unlike in the case of the Upper Pannonian, it is the sandstone layers that are interbedded within the clay-marl sequence rather than clay-marls within sandstones. (Of course, this regional interpretation does not preclude the possibility that sandstones may also include clay-marl intercalations.)

DIAGENESIS OF CLAYEY SEDIMENTS

Since overpressure reservoirs are always connected with sedimentary sequences of extremely high clay content, it seems to be logical that the examination of the characteristics of clays or clay minerals and their diagenetical changes is most important for the tracing of the origin of the pressure in overpressure reservoirs.

Diagenesis is controlled by four factors:

- the depth of burial (overburden pressure),
- the activity of the essential ions,
- the geothermal gradient and,
- the time factor.

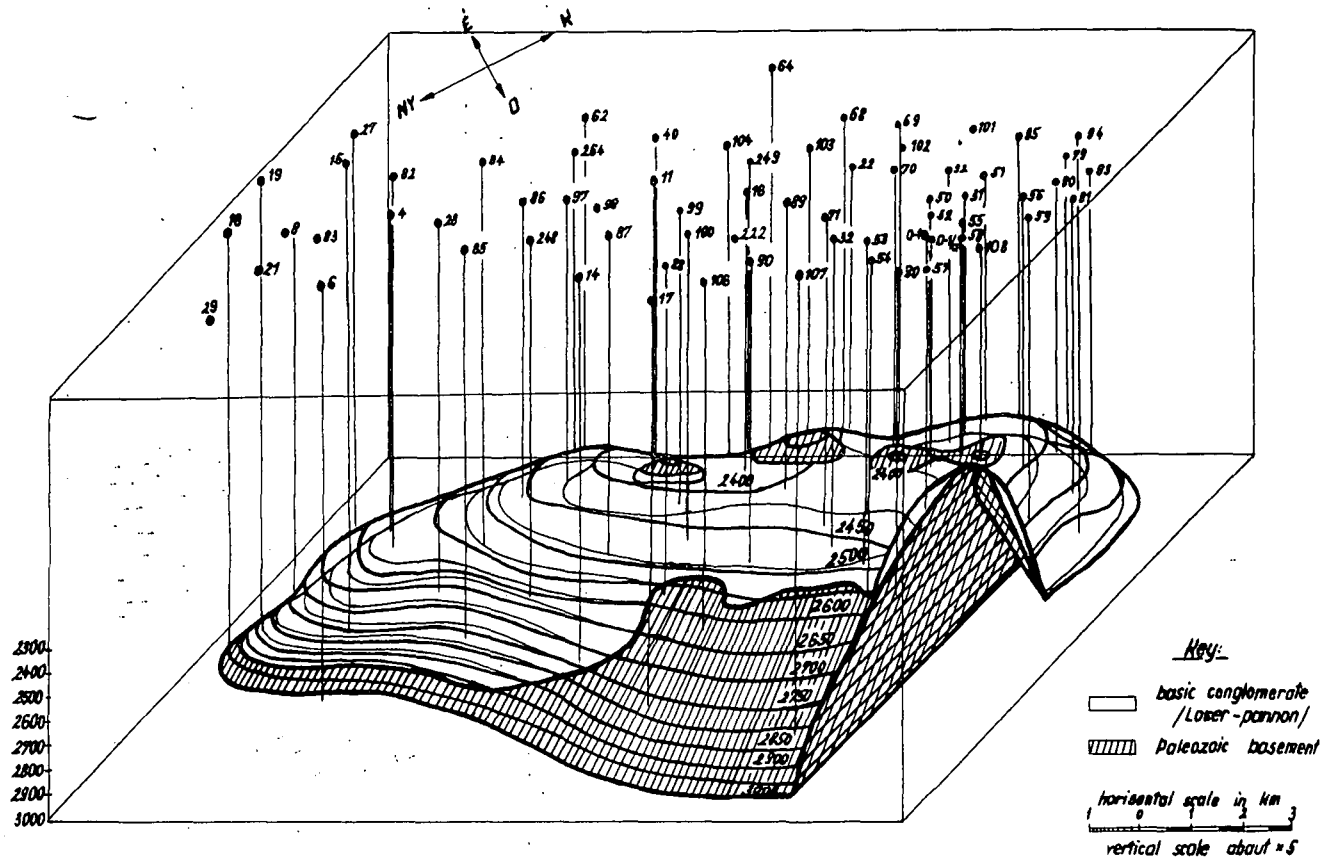


Fig. 5. The extension, line of pinching out and thickness of the conglomerates, resting on the pre-Tertiary basement, are illustrated by an axonometric diagram (in places of intersection the locations of borcholes are also shown).

The clay flakes deposited in the Pannonian inland sea or lake were initially converted into a gel extremely abundant in water. Their original water content equalled 50%. With increasing depth of burial the materials began to release water. Under the effect of compaction, down to 600 — 800 m depth, the material lost most of its water content. Thus water content decreased to about 20 to 30% *(first dehydration phase)*. The water content of clays is dependent upon the properties of the clay minerals present. Expanding clay minerals can adsorb much more water than it is the case with non-expanding ones. Despite the rise in pressure with increasing depth of burial, the water film of 4-molecule thickness, adsorbed to the surface of expanding montmorillonite particles, will not be removed. Nearly 50% of the volume of montmorillonite are bonded water [STEINFINK—GEBHARDT—OLPHEN]. There are two ways for removing hydration water: by electrostatic force or by heating.

Under the effect of *electrostatic attraction*, the capturing of calcium leads to desorption, so that montmorillanite develops into illite. In doing so, it releases again much of its water. According to BURST, POWERS and WEAVER, this process sets in usually at 1500 to 1800 m depth and after a gradual increase, it ceases at 2700 to 3000 or a maximum of 3600 m depth. Consequently, below this depth limit there is no montmorillonite anymore. This is the upper limit of the so-called *"montmorillonite-free horizon"*.

When montmorillonite alters into illite, the water on the crystal faces is desorbed and introduced into the interstices of the grains. The faces get closer to one another. Thus the volume of the individual particles will be reduced, whereas effective porosity and permeability will increase. Because of the rise in pressure provoked by the weight of the overburden, interstitial water will be displaced from the material. The quantity of released water will be approximately equal to the half of the volume of altered montmorillonite.

Consequently, the alteration of montmorillonite into illite will provoke changes in the porosity, permeability and interstitial water content of the sediments. Water content is increased by the fact that, at the innermost water molecule layer, the density of the water hydrated on the montmorillanite faces is higher than normally. (As shown by recent results in crystal chemistry, it may attain even the value of 1.7 g per cm^3.) The average density of the last four water films is 1.4 g per cm^3. In the case of interstitial water, this value is 1.0 g per cm^3 which corresponds to a 40% increase in water volume.

The virtual increase of water, i. e. the history of compaction of clay sediments, is of course dependent on the quantitative ratio of expanding clays to the rest of the clay minerals.

On the basis of the qualitative testing of the pelitic fraction of the Algyő structure the role montmorillonite may have played in the compaction of clay sediments cannot be assessed in quantitative terms.

At closer scrutiny, the problem proves to be even more complicated. In fact, since in Late Pannonian time the conditions for the formation of montmorillonite were substantially more favourable than they were in Early Pannonian time, the quantity of still unaltered montmorillonite available in the Upper Pannonian sediments cannot be used for any conclusion as to the original montmorillonite content of Lower Pannonian clays. However, the present-day montmorillonite content of the Lower Pannonian sediments can be regarded only as a "residue" which escaped illitization — again a result which does not provide any indication of the original quantitative proportions. However, in

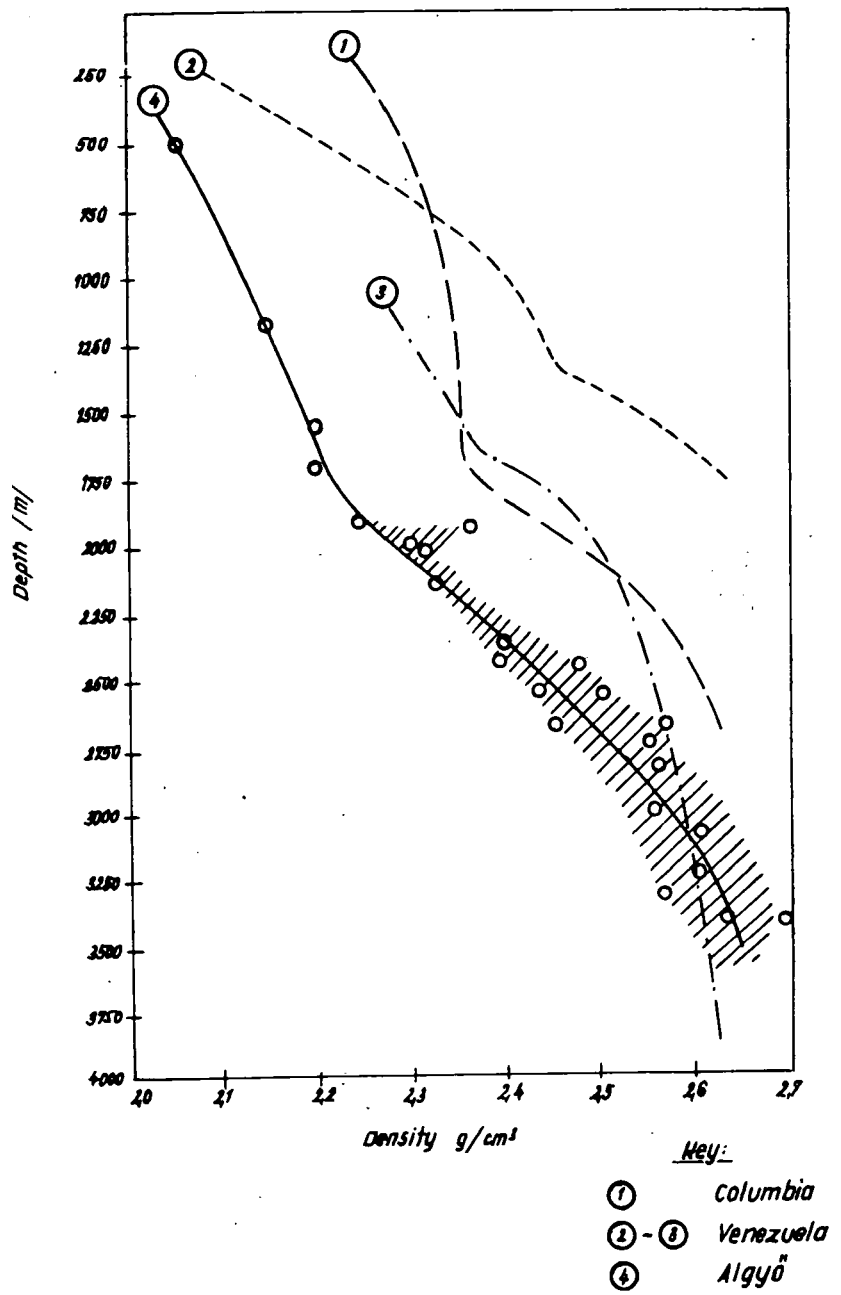


Fig. 6. Clay density versus depth in the Algyő structure as compared with data from other areas.

Early Pannonian time the conditions were favourable for montmorillonitization, so the montmorillonite content can be supposed to have been considerable initially. Summarizing the above, let us conclude that during burial montmorillonite develops into illite according to the above process and this causes an increase in water amount. This can be considered a fact also in examining the Algyő structure, and what still remains a question is to know the size of this water increase — a question to be answered by further testing of clay minerals. Increasing porosity due to alteration will lead to a decrease of clay density. *Fig. 6* illustrates the density of Algyő clays as a function of depth. Just like in the case of the comparative curves, it is at about 1750 m that a characteristic change in density can be observed.

Dehydration may also occur when the uptake of heat due to burial becomes so high that it mobilizes the water molecules according to the following formula:

$$M(H_2O)x + \Delta H \rightarrow M + xH_2O$$

where

$M(H_2O)x$ = the hydrated clay mineral,
ΔH = the absorbed heat (dehydration energy),
M = the dehydrated clay mineral.

Temperature of the sediments

The few temperature values measured in the wells of the Algyő structure are given in Table 1.

TABLE 1

Well number	Depth (m)	Temperature (°C)	Well number	Depth (m)	Temperature (°C)
3	1800	98	47	1713	91
4	2422	142	50	2325	118
4	2012	97	53	2122	112
8	2919	140	56	2300	123
14	2352	120	57	2601	135
16	2513	133	69	2625	140
16	1765	95	81	2550	137
21	3206	156	82	2406	124
21	2118	105	247	1940	97
28	2435	121	264	1838	95
31	2539	134	268	2025	96,5

As evident from *Fig. 7* plotted from the data of the tabulation, the geothermal gradient of the area is < 20 m/°C almost everywhere. Surprizingly enough, the characteristic GGA curve shows a break at point P. A general phenomenon in the Great Hungarian Plain, this change in gradient takes place on the boundary between the Lower and Upper Pannonian. With a view to earlier statements concerning the geology of the area and to the following considerations, the causes of phenomenon can be accounted for as follows. Heat transfer through water-saturated sediments is possible in 3 different ways:

— by the flow of interstitial fluids,
— through the mineral grains of the rock skeleton,
— by heat emission.

On account of the closing effect of the thick clay marls of the Lower Pannonian sequence, the possibility of any upward vertical heat transfer by flow of fluids is precluded, the possible agents of this kind being thermal conductivity and heat emission by the mineral grains of the rock skeleton. Therefore the hanging wall and the foot-wall of the reservoirs become "*overheated*". Overheating promotes dehydration of montmorillonite which leads

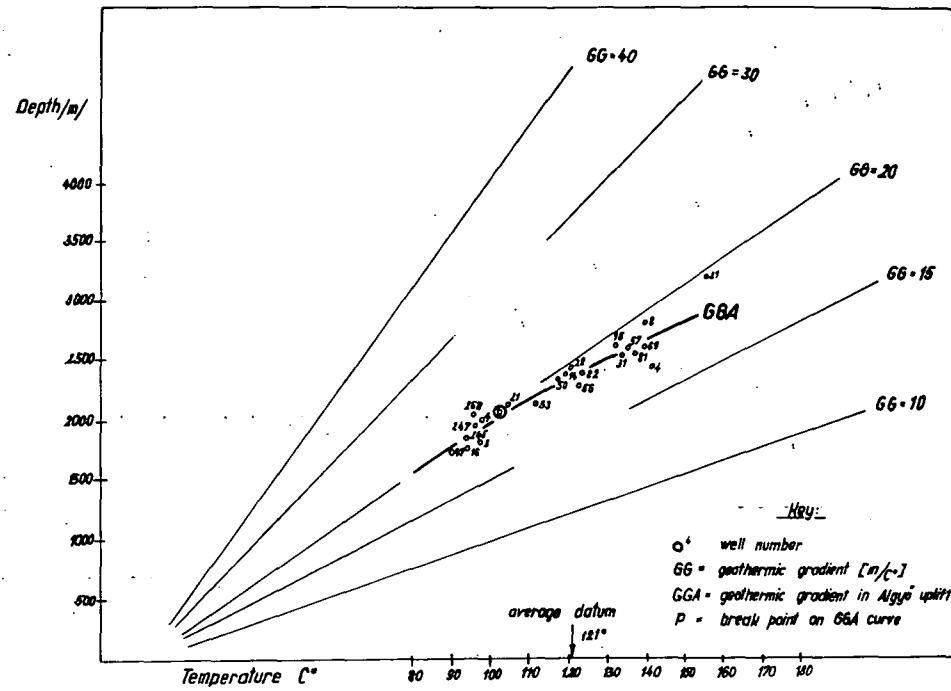


Fig. 7. Geothermal gradient characteristic of the Algyő structure. Break in the gradient is indicated by "P".

to an increase of porosity and, at the same time, to the reduction of thermal conductivity, so that overheating will increase. Since in the Upper Pannonian the continuous hydraulic interconnection of the reservoirs extends up to the surface, it is not only the thermal conductivity of the rock and heat emmission but also the flow of the fluids that are involved in heat transfer. For the setting-in of flow with heat transfer, a difference in temperature is necessary. Movements will increase if a heat-induced change in fluid density brings about a buoyant force. Thus the heat reaching up to the Upper Pannonian formation is unable to accumulate at the same rate as it is in the Lower Pannonian. In other words, a considerable part of heat will "*be wasted*", so that a remarkable decrease of temperature occurs within the Upper Pannonian, a decrease beginning with the Lower/Upper Pannonian boundary. The loss of the hydration water of montmorillonite owing to the illitization of montmorillonite and/or to heating is characteristic of the so-called *second dehydration phase*. The last stage of dehydration, when residual water is released

from clay lattice, appears to develop very slowly, during 10, or possibly 100, million years in dependence on the conditions of burial and the temperature regime. This is the *third dehydration phase.*

Osmosis

It is the third dehydration phase that is most responsible for development of overpressure. Nota bene, though considered to be impervious layers, clays have still some permeability in respect of water. If this were not the case, no compaction could take place. There is no reliable evidence of clay permeability, which can be explained by the possibly non-Newtonian behaviour of water in the pores of clays. As shown by recent observations, the clay and clay-marl layers separating the reservoirs act as semi-permeable films, inducing osmotic pressure between reservoirs containing solutions of different salt concentration.

Well-known is the case when in a natural environment the pressure difference on the two sides of a clay layer was higher than 250 atm [P. M. JONES]. It is plausible that fluid pressure of osmotic origin may exceed the weight of overburden and provoke fracturing or folding of the reservoir. This holds true especially of those places where the load-carrying capacity of clays is reduced by the increase of interstitial water content as a result of the removal of hydration water.

Osmotic pressure across a semi-permeable clay layer is defined by the contrast of salinity in the waters separated. In Table 2 the pressures of a few Neogene hydrocarbon reservoirs and the salt contents of their marginal waters are shown.

TABLE 2

	Name and age of reservoir	Place (m)	Value (atm) of measured pressure	Over-pressure (%)	Total salinity of marginal waters (ppm)
UP	Szőreg—1	1847	183.56	0	4072.89
	Szeged—1	1933	187.5	0	5093.63
	Algyő—2	1934	193.9	0	4966.16
	Algyő—1	1943	193.94	0	4250.00
LP	Algyő—III.	2351	236.72	0	5544.00
	Algyő—IV.	2442	259.6	7	6713.80
	Algyő Basal conglomerate	2506	310.3	24	11519.04
UP	Üllés sandstone	1126	111.5	0	2805.81
Miocene	Üllés conglomerate	2002	322.0	61	30980.00
Miocene	Szank conglomerate	1880	247.0	31	17348.06

Accordingly, at Algyő the salinity of the Upper Pannonian reservoirs of hydrostatic pressure varies between 4000 and 5000 ppm. In the Lower Pannonian, Reservoir III, where the salinity of marginal waters is about 5500 ppm, there is no overpressure yet. The salinity of the reservoir containing Bed IV is considerably higher, about 6700 ppm, whereas the overpressure of the bed amounts to 7%. The contrast in salinity and overpressure between the Lower

Pannonian sandstones and basal conglomerates is yet sharper, as the total salinity of the water in the conglomerate is as high as 11 500 ppm, a property associated with an overpressure of about 24%. On the basis of the above, it seems to be quite natural that in the Miocene of Szank of 17 000 ppm salinity the value of overpressure is about 31% and that in the Miocene conglomerates of Üllés characterizable by even higher salinity this figure is as high as 61%.

Consequently, the origin of pressure can be readily traced back to osmosis due to contrast in salinity, provided that the other conditions discussed above are granted. (However, not all highly saline reservoirs must be pregnant with overpressure!)

Owing to the lack of fluid communication in the Lower Pannonian sandstones, the formation pressures of the deeper-seated beds should — unlike the case of hydrostatic reservoirs — not be necessarily higher than that of the beds of higher structural position. That the pressure in the higher horizons of the Lower Pannonian is yet lower can be readly explained, for because of the grading of saline water into freshwater in the higher horizons, both salinity and osmotic pressure are lower.

Statements

The Pannonian sediments were deposited and buried at a quick pace.

As a rule, pre-Upper Pannonian Neogene reservoirs are closed "lenses", lacking any continuous intercommunication with one another.

The sediments seem to have had a high montmorillonite content.

Below the 600—800 m depth limit, montmorillonite does preserve nothing but its hydration water.

The pressure of the overburden is not sufficient for dehydrating hydration water.

Within the depth range of about 1,800 to 3,600 m montmorillonite develops into illite and much of the strictly bonded water becomes interstitial water.

Dehydration of bonded water takes places at a temperature as low as 110 °C or so.

The temperature of the sediments increases with the depth of burial.

In the Lower Pannonian the geothermal gradient shows a considerable increase, so that dehydration increases.

Production of interstitial water by dehydration and diagenesis of montmorillonite is conducive to an increase of the porosity and permeability of the clay layer and, consequently, to a reduction of its density, load-carrying capacity and heat transfer. Dehydration is associated with the growth of water volume, for the density of water is reduced from the average, 1.4 g per cm^3, to 1.0 g per cm^3.

The salinity of waters in the Lower Pannonian conglomerates and the Miocene sequence increases with depth by leaps and bounds.

If the adjacent reservoirs separated by a clay layer contain waters of different salinity, a pressure difference can be induced by osmosis, a process during which the clay layer acts as a semi-permeable film.

The weight of the overburden brings about compression in the unconsolidated sediments. If the rock skeleton is not strong enough to take up the entire load, a part of geostatic pressure will be kept by the fluids.

Summary

The Miocene reservoirs resting on the basement, i. e. the presumably transgressive Pannonian basal conglomerates and the Lower Pannonian sandstones characterized by hiatuses due to rapid sedimentation and unsteady subsidence, are separated by thick clay sediments. So there is no continuous fluid communication between them. On account of the increasing weight of the overburden, the uncompacted clays released their water which passed over into the interbedded conglomerates and sands where water was flowing toward spaces of lower pressure. In the reservoirs pinching out, the pressure increased rapidly, to attain a value at which the waters of the reservoirs were squeezed across the overlying clays. This slow upward flow was gradually decreasing in rate, as the osmotic force resisted the process. The plastic clay layers behaved as semi-permeable films or *"ion sieves"*. Letting the water flow through, they blocked the movement of the ionized substances in solution. Thus in the deeper horizons an increase of salinity occurred, a phenomenon which was associated with the leaching of saline waters occurring in the so-called *"zone of volatilization"*. (Nota bene, these horizons were supplied with *"salt-free"* water from the formations underneath.) This phenomenon took place in hydrostatic reservoirs. Osmotic pressure, which was oriented toward the salt-water reservoir, could resist the attacking stresses and thus prevent water from being removed. After a gradual increase it finally reached the value of equilibrium with the outward-acting reservoir pressure, so that the water stopped flowing through the clay layer.

During burial, under the effect of the increasing weight of the overburden, the afore-mentioned pressure equilibrium may have been upset and again a flow may have set in until a new pressure equilibrium was reached. Since in the Lower Pannonian sediments the upward flow of water was hindered by an upward heat flow, it decreased greatly and the reservoirs became overheated. With increasing reservoir temperature, vapour pressure increased, while the density and viscosity of the water diminished. Osmotic pressure became stronger.

Thermal dehydration of montmorillonite, or its alteration into illite with the bonding of potassium, resulted in interstitial water which was equal in volume to the altered montmorillonite. Under the increasing weight of rock, the resulting water was again squeezed from the clay into the reservoirs. This resulted in a little decrease in salinity, but the surplus water volume, which was further increased by the volume increase due to the decrease of water density, went on growing and led to higher reservoirs pressure. Pressure equilibrium began to be re-established. The water squeezed through the clay layers could be accompanied only by dissolved solid substances and gases. As a result of the pressure decrease and chemical reaction, carbonates and silicates precipitated in the upper part of the hanging clay formation, thereby facilitating the closure of the overpressure reservoir. This fact accounts for the comparatively high density and poor drilling characteristics observed in the clays closing up the overpressure reservoirs.

Accordingly, the increased volume of the reservoirs and the osmotic pressure produced by molecular forces as well as mechanical compression brought about an overpressure; at the same time, because of the precipitation of solids the virtual permeability of the overburden decreased practically to zero and thus preserved overpressure for millions of years.

Should one extrapolate the genetic interpretation of overpressure in the reservoirs of the Algyő structure to the Szank and Üllés areas, this would not preclude the possibility that the origin of other overpressure reservoirs to be explored in Hungary may be traced back to different causes.

Overpressure reservoirs forming closed systems

Theoretically, the overpressure reservoirs are closed systems of definite, constant volume.

Three causes of the closure of reservoirs are known to exist:

— pinching out,
— changes in lithology (eventually, cementation),
— faulting (eventually, block-faulting).

Mechanical compression can also produce overpressure within a closed system, as observable during compaction in unconsolidated rocks. If the contacting mineral grains, making up the rock skeleton of the reservoirs and behaving like "*supporting pillars*" carrying the sedimentary overburden, are unable to bear the increasing load or if they are suddenly attacked by tectonic stresses, the void volume will diminish and/or a part of the formation pressure will be transmitted to the void-filling fluids, becoming fluid pressure. Accordingly, in the procces of consolidation:

overburden pressure + fluid pressure = geostatic pressure.

The less graded the material of the reservoir, i. e. the higher its clay content, the more it is liable to diminish its void volume. Squeezing of clays into the pores (voids) under the effect of the pressure of sand grains may diminish permeability or render the material impervious.

Deformation of quartz grains and their subsolution at the contacts in deep burial produces a marked decrease in porosity even in sorted sandstones. The number of contact points increases with depth, the sand grains tend to be evenly distributed under the load.

If lateral pressure is also involved in mechanical compression (e. g. due to orogenesis), then overpressure can substantially exceed the geostatic value and the upper pressure limit is defined by the resistance of the strata in absence of fractures, faults or slips.

Osmotic pressure develops between reservoirs of different salinity. The separating clay layer behaves as a semi-permeable film. The sharper the contrast in salinity between the waters of the two reservoirs, the higher the resulting pressure difference.

Joints action of both mechanical compression and osmotic pressure brings about such a fluid pressure in which the combined effect of the osmotic pressure and geostatic pressure is diminished solely by the load taken up by the rock skeleton:

Fluid pressure = osmotic pressure + geostatic pressure = overburden pressure

or, respectively,

geostatic pressure = fluid pressure + overburden pressure = osmotic pressure

Changes of temperature in fluids provoke essentially greater volume changes than it is the case with temperature rise in rocks.

Thus the pressure of the reservoirs will increase. (The thermal expansion of sandstones is $[30 \pm 6] \cdot 10^{-6}$ or so, that of oil, water and gas being well-known.)

Chemical, physico-chemical changes

In reservoirs the original minerals may be dissolved and recrystallized; non-ionized solid particles may get into the pores of sandstones in the course of vertical percolation during compaction. Thus the void volume may be decreased by the cementing material and salt precipitations, a phenomenon conducive to pressure increase. Polymerization of hydrocarbons consisting of comparatively larger molecules may result from bacterial or catalytic reactions, radioactive decay or changes in temperature, phenomena which can also increase the reservoir pressure.

Communication with a reservoir of higher pressure

Upon tectonic stresses or in other ways, a reservoir closed at its top may come into communication with a deeper-seated oil- or gas body of higher pressure. If the channelways between that body and the reservoir (channelways which may later be clogged) are filled up by gas or oil, the upper reservoir may develop into an overpressure pool which preserves its overpressure for a long time even in terms of the geological time scale. Fluid movement between the two beds will persist as long as $P_a > (P_f + h\varrho)$, where

P_a = the pressure of the lower reservoir,
P_f = the pressure of the upper reservoir,
h = the vertical distance between the two reservoirs,
ϱ = the density of the upward-flowing fluid.

The fluids will stop moving when

$$P_a - P_f = h\varrho$$

The variation of pressure depends on the relative volumes of the two reservoirs and on the volume of the communicating channelway.

Increase in water content in the reservoir is brought about by the illitization of montmorillonite and/or its thermal dehydration. The change of hydration water into interstitial water is accompanied by an increase in water volume due to the expansion of water from the average value, 1.4 g per cm^3, to 1.0 g per cm^3.

Changes in the depth of burial

If a closed reservoir (which may originally have had a hydrostatic pressure and in which the pressure conditions do not change anymore) gets closer to the surface (e. g. as a result of denudation or uplift), the pressure gradient will increase and an overpressure set in.

Dynamic effects

Seismic waves (which caused numerous expansions and compressions in geological history), sea currents (tidal waves or, eventually transgression-

regression), varying atmospheric pressures and the so-called *"vibrators"* affect the reservoirs with some delay. Thus it is by compacting or even fracturing that they influence their pressure conditions. (Examples are known, where the yields of the oil-wells of certain areas showed sudden changes after earthquakes.)

Overpressure reservoirs of open system

In the overpressure systems discussed earlier, one of the basic conditions was to have *"closed"* reservoirs. However, such reservoirs are also known in which the pressure gradient is different from the normal despite the fact that fluid communication is continuous up to the land surface. It is advisable to call these: *"overpressure reservoirs of open system"*.

In case of great thickness the pressure gradient of the bed may be substantially higher than the hydrostatic value which can be measured in the marginal waters of the reservoir. In case of a gas-capped oil-bed the pressure P measured at depth H at the oil-water interface will produce a pressure gradient equalling P/H, which is of hydrostatic value if fluid communication with the surface is continuous. If the pressure is examined at the gas-oil interface, a lower value ($P - h_0\varrho_0$) will be obtained, in dependence on the thickness h_0 and density ϱ_0 of the oil body.

If the thickness of the gas cap is h_g and its average density ϱ_g, then at the top of the gas cap the following formula will be valid:

$$P - h_0 \cdot \varrho_0 - h_g \cdot \varrho_g$$

Thus, calculated for the gas-oil interface, the pressure gradient will be:

$$P - h_0 / h_g - \varrho_g$$

while at the top of the gas cap

$$P - h_0 \cdot \varrho_0 - h_g \cdot \varrho_g / H - h_0 - h_g$$

It is especially in mass reservoirs that such an increase in pressure gradient and the resulting overpressure may be significant. Therefore in the gas cap an overpressure (the value of which may be high) can be observed and it is only with a more detailed knowledge of the reservoir that one can point ou that the causes responsible for the phenomenon are other than pressure anomaly. Consequently, the pressure gradient within one reservoir is a function of depth and fluid density.

The overpressure due to great thickness is illustrated by the following example:

Data of the reservoir:

depth of water-oil interface (H) = 2000 m
thickness of oil body (h_0) = 100 m (10^4 cm)
thickness of gas body (h_g) = 200 m (2.10^4 cm)
depth of the top of gas cap ($H-h_0-h_g$) = 1700 m
density of oil in the reservoir (ϱ_0) = 0.72 kg/dm^3 = $7.2 \cdot 10^{-4}$ kg/cm^3
density of gas in the reservoir (ϱ_g) = 180 mg/cm^3 = $1.8 \cdot 10^{-7}$ kg/cm^3.

Pressure values:

at the water-oil interface (P) $\cong$ 200 kg/cm^2
at the oil-gas interface ($P - h_0\varrho_0$) $\cong 200 - 10^4 \cdot 7.2 \cdot 10^{-4}$
$= 200 - 7.2 = 192.8$ kg/cm^2
at the top of gas cap $P - h_0\varrho_0 - \varrho_g h_g) \cong$
$\cong 200 - 7.2 - 2 \cdot 10^4 \cdot 1.8 \cdot 10^{-7} =$
$= 200 - 7.2 - 3.6 \cdot 10^{-3} =$
$= 200 - 7.2 - 0.0036 =$
$= 192.7964$ kg/cm^2,

since at the top of the gas cap (at 1700 m) the pressure is 192.79 kg/cm^3 instead of the hydrostatic value, 170 kg/cm^3, thus an overpressure of 13% or so will result.

Pressure gradient values:

at the water-oil interface P / H = 200 / 2000 = 0.1 at/m
at the oil-gas interface $P - h_0\varrho_0 / H - h_0 \cong$
$\cong$ 192.8 / 2000 — 100 $\cong$
$\cong$ 0.101 at/m
at the top of gas cap $P - h_0\varrho_0 - h_g\varrho_g / H - h_0 - h_g \cong$
$\cong$ 192.79 / 2000 — 100 — 200 $\cong$
$\cong$ 0.113 at/m.

Morphology may also be responsible for overpressure. In case of a rough land a system can develop, in which a continuous fluid communication with the surface is granted, but because of the incision of a deep valley the piezometric level does not coincide with the surface of sediment. Since the hydraulic head of the water percolating in the reservoir corresponds to the value of the piezometric level, it is obvious that wherever the surface sinks below the piezometric level, an overpressure can be observed and the pressure gradient will increase.

Communication with a higher-pressure reservoir without establishment of a pressure equilibrium

If the fluids tend to migrate towards a hydrostatic oil- or gas body because of intercommunication (which was mentioned among the causes of overpressure), the pressure will increase in this latter. This is a common phenomenon in hydrocarbon-bearing structures, where owing to the poor completion of wells an intercommunication with higher horizons (*"dismigration"*) can be established in many cases. In a reservoir of increased pressure the equilibrium of pressures is not established for a long time, not even when the channelway of communication is clogged. Since fluid communication with the surface is continuous and though the pressure equilibrium ought to be re-established in principale, this re-establishment is delayed by the frictional resistance of the rocks, the water binding energy of mineral grains, the capillary forces, etc. (Because of the above causes, the individual member of a hydrostatic reservoir system in the Upper Pannonian can be considered to represent separate hydrodynamic units; the oil and gas bodies can be exploited to pressure values substantially lower than the hydrostatic pressure, or in lack

of exploitation they will preserve their temporary overpressure for a long time. The rate of "*pressure regeneration*" depends on the physical properties of rocks and fluids, on the size of divergence from normal pressure, on temperature conditions and on the connections of single oil bodies and reservoirs. Therefore "*regeneration*" may take considerable time even in terms of the geological time scale.)

Genetic classification of overpressures

Overpressure reservoirs of a closed system

Physical causes:

— mechanical compression
— changes in temperature
— communication with a reservoir of higher pressure
— increase of water content in the reservoir
— changes in the depth of burial
— dynamic effects

Chemical and physico-chemical causes:

— chemical and physico-chemical changes
— osmotic pressure.

Combined effect of various physical and chemical agents and/or of several of the above-listed causes.

Overpressure reservoirs of open system

— great thickness of formation
— morphological causes
— communication with a reservoir of higher pressure without establishment of pressure equilibrium.

DISTRIBUTION AND FLUID CONTENT OF OVERPRESSURE RESERVOIRS

According to literature, in the uppermost 1500 to 1800 m or so, no overpressure reservoir of closed system has been usually encountered, and the greatest divergences from normal pressure were observed within the 1800 to 3600 m depth range. Any increase of pressure below this limit implies an overpressure with the hydrostatic pressure added to. In oil geology, compaction is important from two points of view:

— the development of the structure above a rough surface as a result of sedimentation and compaction;
— the waste, i. e. removal, of fluids indispensable for oil and gas migration.

Squeezed out of the clay rock as a result of compaction, the water will carry away the available organic particles, oil and gas, either in emulsion or in solution. Origin and primary migration of oil and gas are connected with the diagenesis of clays, taking place in the second dehydration phase dicussed earlier, at varying depths within the range of 1500—1800 m (minimum) and 3600 m (maximum), under the effect of temperature and other factors.

In absence of percolation, non-expanding illite and kaolinite are not suitable for serving as mother rock. Therefore the montmorillonite content is very important for oil geology.

The most favourable depth of oil and gas formation is defined a priori — a fact essentially determining the choice of most prospective areas. However, because of the great possibility of migration the zone of oil and gas accumulation will grow wider upwards, whereas with the deepening due to burial it will show a downward widening.

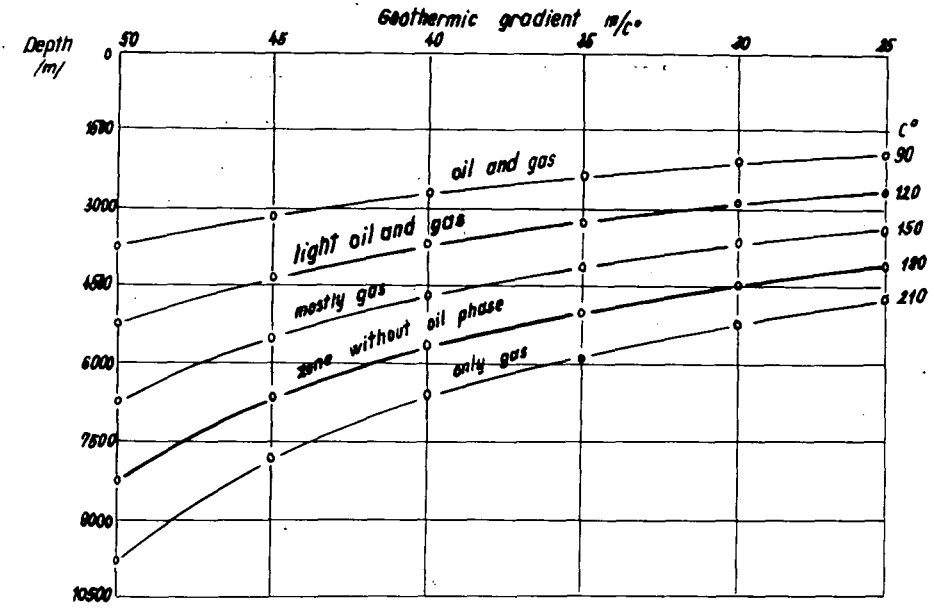


Fig. 8. The figure shows that at temperatures higher than 180 °C only gas accumulations are expected to occur.

In the deep-seated reservoirs the properties of oil and gas will change, as the oil in the reservoir rock is extremely sensitive to both pressure and temperature. Thermal decomposition (cracking) will lead to a decrease of density in the oils, since the small number of giant molecules are replaced by a great number of smaller ones, forming a more stable mixture under conditions like these. Because of condensation the aromatic compounds will develop into polycyclical molecules of higher molecular weight, losing their lateral chains. The final product of the process will be graphite. The paraffines will develop into light compounds, finally, into methane having a minimum of free enthalpy. In *Fig. 8*, borrowed from the literature, curves of oil and gas deposits, plotted against depth and temperature on the basis of theoretical considerations and the results of drilling a few hundred wells of great depth, have been presented. It is evident from these, that overpressure reservoirs may contain both oil and gas and that they are not connected preferentially with gas reservoirs at all. It is worth mentioning, however, that in overpressure reservoirs too it is the gas phase that predominates.

REFERENCES

Бкаиров, А.А, Васильев В. Г. [1967]: Вопросы роисков и разведки не нефтяних и газовых месторождений на VII. Всемирном Нефтаном Конгресс

Balogh, K., Kőrössy, L. [1968]: Tektonische Karte Ungarns im Masstabe: 1 : 1 000 000. Acta Geol. Acad. Sci.. Hung., *12*, 255—262.

Dank, V. [1964]: A dél-alföldi kőolaj- és földgázkutatások. Bányászati Lapok *97*, 775—788.

Dank, V. [1965]: A dél-alföldi neogén medencerészek mélyszerkezeti viszonyai és kapcsolatok a dél-baranyai és jugoszláviai területekkel. Földt. Közl., *95*, 123—129.

Dank, [1966]: Szeged környéki szénhidrogén kutatások. Bányászati Lapok, *99*, 122—136.

DANK, V., BÁN, Á. [1966]: Az algyői kőolaj- és földgáz-előfordulás földtani viszonyai és termeltetésének elvei. Földtani Kutatás 1966. évi különszám.
HOBSON, G. D.: Some Fundamentals of Petroleum Geology. Oxford University Press.
HUTCHINSON, C. A., DODGE, C. F., POLASEK, T. L. [1961]: Indentification Classification and Prediction of Reservoir nonuniformities Affecting Production Operations. Journal Petrol. Techn., March.
JONES, P. H. [1969]: Hydrodynamics of Geopressure in the Northern Gulf of Mexico Basin. Journal Petrol. Techn., 1969, July, 803—810.
KERTAI, GY. [1962]: A magyarországi földgáztelepek kialakulásáról és továbbkutatásuk alapelvéről. Föld. Közl.,92, 274—279.
KERTAI, GY. [1960]: A magyarországi szénhidrogén-kutatás eredményei 1945—1960-ig. Föld. Közl., *90*, 406—418.
KÖRÖSSY, L. [1963]: Magyarország medenceterületeinek összehasonlító földtani szerkezete. Föld. Közl., *93*, 153—172.
LANDES, K. K. [1967]: Eometamorphism, and oil and gas in time and space. Bull. Amer. Assoc. Petrol. Geol., 828—841.
LEVORSEN, A. I., FREEMEN, W. H. *et. al.* [1958]: Geology of Petroleum. San Francisco.
POWERS, M. C. [1967]: Fluid-release Mechanisms in Compacting Marine Mudrocks and their Importance in Oil Exploration. Bull. Amer. Assoc. Petrol. Geol., 1240—1254.

Соколов, В Л. Лоджевская М, И. [1967]. Эффективность разведочного бурения на больше глубины б США. Теология нефти и газа.

DR. ATTILA SOMFAI
Great Plain Drilling and Prospecting Enterprise
Dorozsmai út 75, Szeged, Hungary

GEOLOGICAL, MINERALOGICAL AND PETROGRAPHICAL INVESTIGATION ON NAGYKŐMÁZSA HILL AT MISKOLCTAPOLCA

GY. VITÁLIS AND MRS. J. HEGYI-PAKÓ

INTRODUCTION

In order to explore the raw material reserves of the Hejőcsaba Cement and Lime Works the Central Research and Design Institute for Silicate Industry carried out detailed geological prospecting on the Nagykőmázsa Hill at Miskolctapolca, in the years 1966—1968.

On the area of study, which joins the actual Nagykőmázsa quarry of the HCM *(Fig. 1)*, detailed mine geological surveying, 24 core drillings of about 1795,5 metres, hydrogeological observations, and complex geophysical measurements have been made (radioactive logging in every borehole). Multilateral and numerous tests have been made on the core samples in order to establish their mineralogical and petrographical composition and their qualification for use in cement and lime industry.

The present paper deals with the principal results of the aforesaid examinations.

GEOLOGICAL CONDITIONS

Geological setting. The Nagykőmázsa Hill at Miskolctapolca consists of Ladinian limestone (total thickness about 700 metres), of predominantly light grey colour, with local patches of rose-colored calcite. *(Fig. 1).* The limestone is exposed on the greatest part of the explored area; at some places; however, it is covered by 0,3—2,5 metres of brown and reddish-brown, silty-clayey loam of Pleistocene age. The latter is thicker at the base of the slopes, growing thinner upwards.

The uniformity of the strongly karsted limestone series is disturbed by clayey contaminations filling up caverns and open rock fissures, with subordinate occurrences of bigger calcite veins and hydrothermal effects. The brown and reddish-brown filling of the karstic cavities, caverns and wider cleavages is identical with the Pleistocene cover in both mineralogical and petrographical respects, so it can be considered as its derivate. The less common flesh-red, sometimes grey clays, on the contrary, are older (Tertiary) residual sediments due to tropical-subtropical weathering.

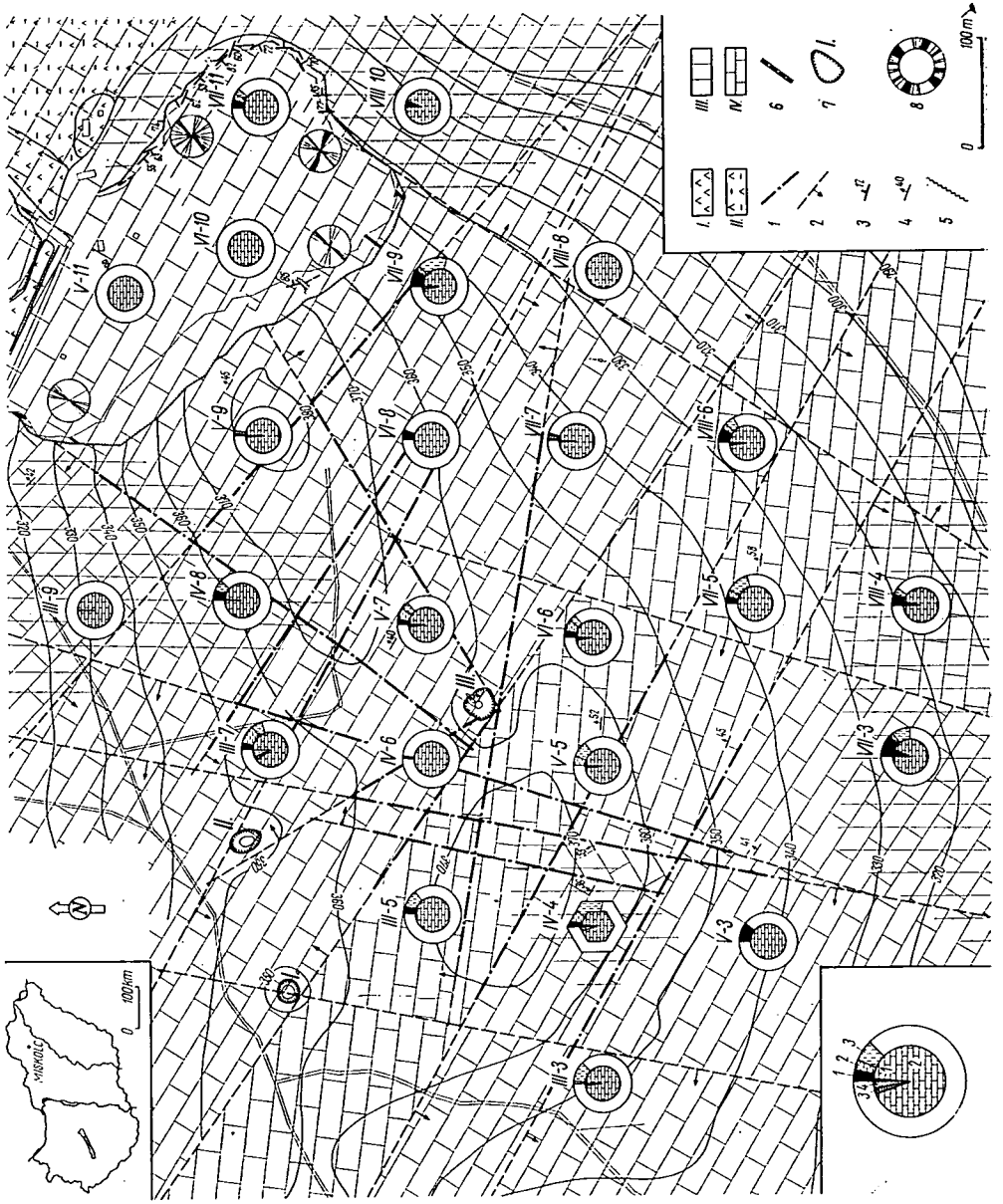


Fig. 1.

Calcite veins and other traces of hydrothermal activity are indicative of a possibly Pleistocene hot spring influence.

Geological structure. Nagykőmázsa Hill and its immediate surroundings belong to the NE wing of the Répáshuta—Hollóstető—Bodzáskút anticline range of the SE Bükk Mountains. The folded forms, brought about by older tectonic movements, have been strongly dismembered by NNE—SSW and perpendicular WNW—SES oriented younger faults; the actual structural pattern is mostly faulted.

The mostly unstratified and very stressed limestone series dips at 45° to the NNE. The lithoclases measured in the quarry strike preferentially WNW—SSE, NNE—SSW and NE—SW. The same is true for the measured smaller faults and for those detected by geophysical measurements. Fault planes dip at an average angle of 70°.

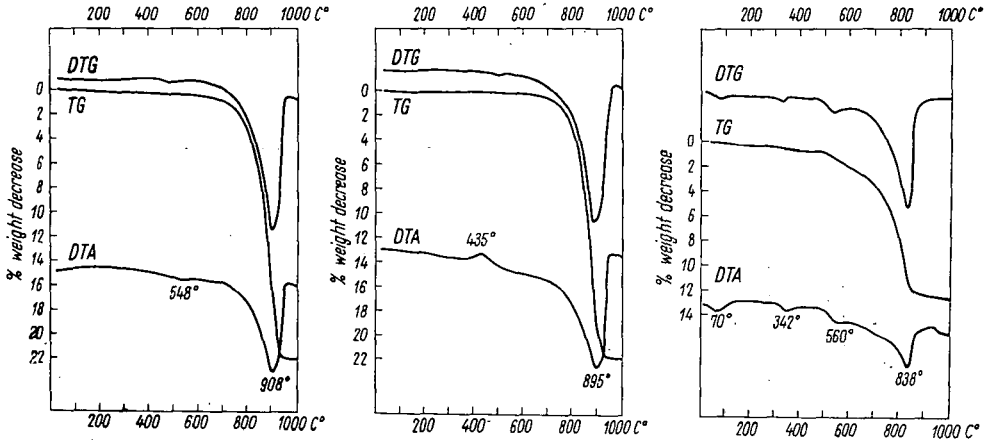


Fig. 2. Derivatogram of the limestone sample with hydrothermal traces from 50,0 depth of borehole V—3.

Fig. 3. Derivatogram of the limestone sample with hydrothermal traces from 239,0 m depth of borehole V—7.

Fig. 4. Derivatogram of the red clay from the fissure of the limestone.

The calcite veins and fissures filled up by clayey material observed in the quarry are oriented approximately NE—SW. Accordingly, open fissures, calcite veins, and clayey contaminations are likely to be oriented similarly, in contrast to the conditions established for the Hungarian Central Mountains.

Fig. 1. Mining geological map of the Nagykőmázsa limestone exploration area. Diagram and legend (bottom left). Inner circle: percentages of the geological formations intersected by drilling from the surface down to 285 metres a. s. l. 1) clay cover, 2) limestone, 3) limestone with clayey contamination. Outer circle: percentages, down to the same level, of 1) cavities, 2) clayey fillings, 3) cataclastic intervals, as detected by radioactive logging. (In borehole represented by a hexagon — to 324 m a. s. l. only.)
Legend (bottom right). I. waste stockpile (Holocene); II. slope debris (Holocene-Pleistocene); III. clay cover (0,3—2,5 m thick). Pleistocene; IV. Limestone (Ladinian), (> 250 metres). 1) fault detected by geoelectric measurement, 2) fault constructed by structural, geoelectrical measurements and geomorphological observations, with the assumed dip; 3) fault dip; 4) stratum dip; 5) calcite vein; 6) fissure filled up by clay; 7) dolina; 8) synthetizing lithoclase diagram.

TABLE I.

Chemical analyses

Symbol of the sample (m)	Name of rock	Loss on ignition	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	SO_3	$CaCO_3$
		Percent by weight										
Nagykőmázsa V—7/210,0	Limestone	43,60	0,15	0,01	0,03		55,30	0,10	0,27	0,07	0,32	98,76
VI—6/20,0	Limestone with hydrothermal traces	42,55	1,62	0,80	0,44		53,95	0,10	0,22	0,08	0,06	96,30
V—3/50,0	Limestone with hydrothermal traces	43,12	0,75	0,75	0,12		54,39	0,19	0,24	0,09	0,05	97,09
V—7/235,0	Limestone with hydrothermal traces	43,37	0,68	0,11	0,54		54,63	0,09	0,25	0,08	0,08	97,51
limestone quarry	red clay	12,11	44,98	16,73	6,16	1,47	11,15	2,17	0,18	4,80	0,01	19,90
limestone quarry	gray clay	5,79	53,33	20,77	6,96	1,90	2,23	3,00	0,19	6,32	0,08	3,98
overburden	pleistocene clay	9,19	58,04	18,91	7,85		2,23	1,01	0,45	1,53	0,10	3,98
max. and average value analyses from 56 limestone samples	minimum	42,96	0,05	0,01	0,01		54,36	nyom	0,02	0,01	nyom	97,06
	maximum	43,84	0,82	0,31	0,84		55,87	0,65	0,49	0,09	0,32	99,78
	average value	43,51	0,25	0,09	0,08		55,31	0,39	0,22	0,05	0,06	98,78

The faults and fissures of WNW—ESE strike observed in the quarry are closed; consequently, in such direction no hydrothermal alterations, calcite veins or clayey fillings are likely to occur.

MINERALOGICAL AND PETROGRAPHICAL STUDIES

Chemical and thermic examinations. The investigation results of some rock types showing hydrothermal alterations should be presented.

Figs. 2 and *3* show the derivatograms of two limestone samples from different boreholes and depths. The chemical composition of these samples is given in Table *I*, along with the chemical composition of the predominant "pure" limestone of the area. Some orientative spectrographic data are to be found in Table *II*. The extreme and average value of the complete chemical analysis of 56 limestone samples, representative of the entire area, are also represented in Table *I*.

It is obvious from the data of Table *I* that the $CaCO_3$ (calcite) content of the hydrothermally altered rock samples is lower than the average (98%) of the "pure" limestone. The difference is due mainly to the higher percentage of the Fe, Al and Si contaminations. The thermic (derivatographic) and X-ray tests reveal the presence of quartz, clay minerals and pyrite, brought about by the hydrothermal influence.

On the DTG and DTA curves of *Fig. 2* beside the well developed calcite peak at 900 °C one can observe a quite well marked endothermic effect between 500 and 600 °C. The X-ray diagram of these samples indicates the presence of quartz and kaolinite. The thermic peak suggests that these are only slight traces.

On the DTA curve of *Fig. 3* appears an exothermic peak at 435 °C, due to pyrite oxidation. Accordingly, the iron oxide content of these samples is higher indeed. (According to our experience, such small amounts of pyrite can not be detected by X-ray diffractometry in carbonate rocks.)

In the fissures to be seen in the limestone quarry, there is red (subordinately grey) clay, considered as a product of Tertiary tropical-subtropical karstification. The near-surface cracks are filled up by the brown to reddish brown silty, clayey loam of the Pleistocene cover. For the sake of comparison, the results of the investigations on these are also shown (chemical composition in Table *I*, spectrographic data in Table *II*). According to the thermoanalytic and X-ray tests, the red clay contains illite, kaolinite, quartz, calcite, and gibbsite, the grey one — illite, kaolinite, quartz, calcite, while the Pleistocene clay consists of illite, kaolinite, quartz, feldspar and organic substances. Spectrographic data suggest that both the red and the grey clays have been affected by hydrothermal alteration.

Thin section studies. The genetical characteristics of the Ladinian limestone are well illustrated by the thin section photos (cross-polarized light), *(Photos 1—8)*, photographed and studied by I. Csordás, geologist, Mineralogical and Petrographical Department of the Technical University of Heavy Industries, Miskolc.

The pelitic microspar matrix, characteristic of the limestone studied, is well observable in all thin sections. The tectonically rather affected nature of the area is clearly demonstrated by small nodular or lenticular macrospar

TABLE II.

Informational spectral analyses

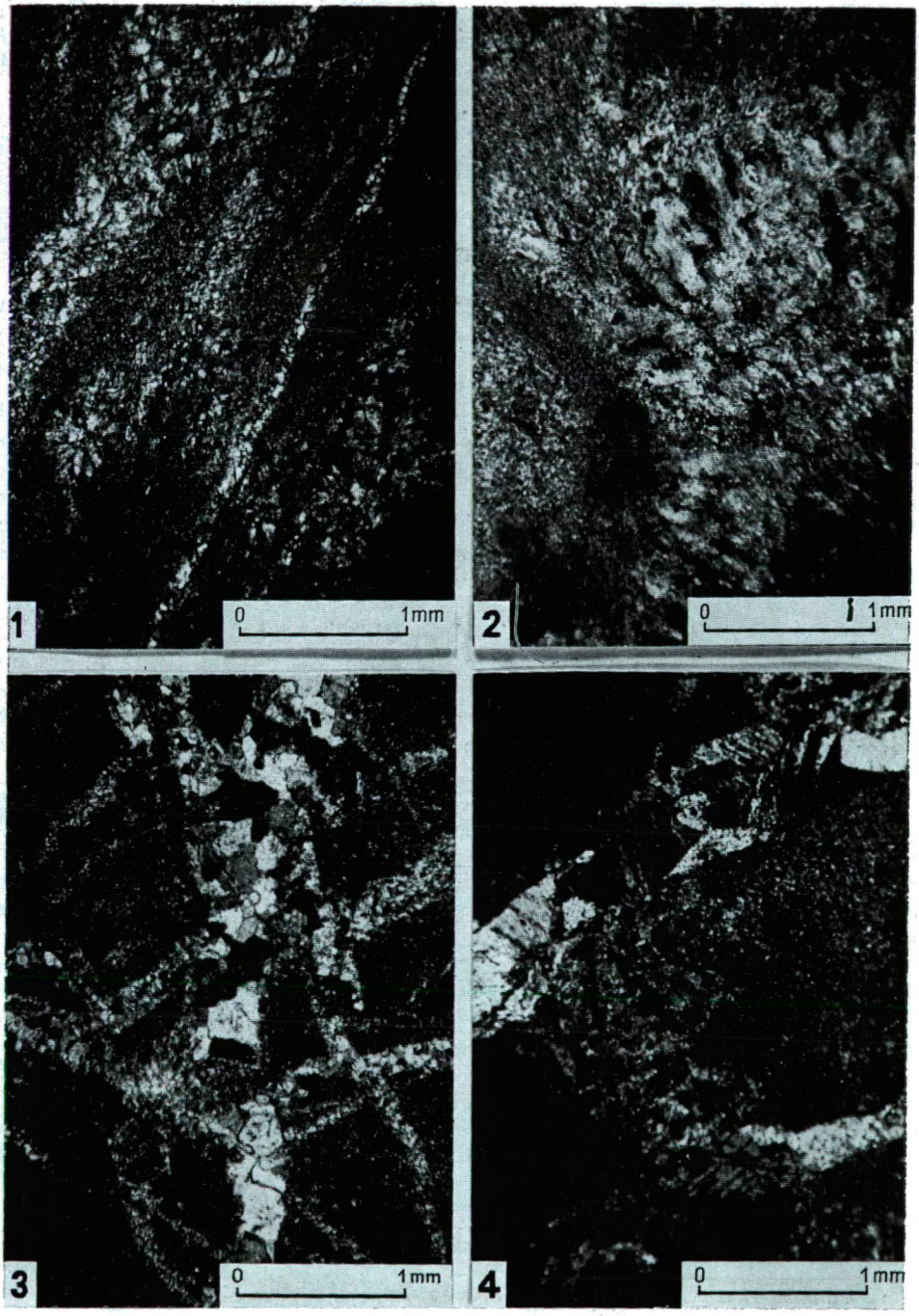
Name of rock	approx. % traceable element				
	10^{1}	10^{0}	10^{-1}	10^{-2}	10^{-3}
bore hole V—7. limestone from depth 210,0 m	Ca	Mg	Cu Si	Mn Pb	Sn Fe Al
bore hole VI—6. limestone with hydrothermal traces from depth 20,0 m	Ca	Mg	Fe Si Al Mn Cu		Ni
bore hole V—3. limestone with hydrothermal traces from depth 50,0 m	Ca	Mg	Al Mn Fe Si	Cu	Cu
bore hole V—7. limestone with hydrothermal traces from depth 239,0 m	Ca	Mg	Fe Si Mn Al	Mn Cu	Ni
red clay from fissures of Nagykőmázsa limestone quarry	Si Al	Ca Ti Mg	Fe V K Cr Ni	Na	Co B
gray clay from fissures of Nagykőmázsa limestone quarry	Si Al	Mg Ti Ca	Ni V Cu Cr Fe K Co	Na	Mn B
pleistocene clay Nagykőmázsa	Ca Si Fe	Mg Al Ti V	Mn Cu B	Na Ni	Cr Pb

bodies of subparallel orientation *(Photo 1)*, by folded forms at the boundary between the macro- and the microspar *(Photo 2)*, by the cataclastic texture *(Photo 3)*, and by nodular, medium-grained macrospar with pressure twin lamellae, formed within the predominant pelitic microspar, and affected by dissecting tectonic movements and by formation of a new generation of hydrothermal macrospar with pressure twin lamellae. *Photo 4)*.

Younger tectonic and hydrothermal effects are demonstrated by *Photos 5* to *8*. Such are: several generations of a tectonically controlled vein network *(Photo 5)*; coarse macrospar formed along tectonic lines, of first and second generation, with twin lamellae *(Photo 6)*, second-generation calcite vein crossing the vein network of the first generation, with a third-generation rim *(Photo 7)*, and a microfault *(Photo 8)*.

These thin section photos reflect very well the tectonic pattern observed in this area. The angle of the big fault system *(Fig. 2)* corresponds well to the angles closed by the calcite veins to be observed in thin sections, although the thin sections are not oriented.

Phot. 1. Thin section of the Ladinian limestone from 105,0 m of borehole V—7
Phot. 2. Thin section of the Ladinian limestone from 57,3 m of borehole III—5
Phot. 3. Thin section of the Ladinian limestone from 30,0 m of borehole V—6
Phot. 4. Thin section of the Ladinian limestone from 58,0 m of borehole VII—5



Phot. 1—4.

In conclusion, the hydrothermal activity of probably Pleistocene age, which has affected the Ladinian limestone series of Nagykőmázsa Hill, has produced no considerable alterations. Only traces of the characteristic hydrothermal parageneses have been found.

The clayey contaminations brought about by the hydrothermal activity can be discerned on the basis of the examinations performed from those due to karstification or to other types of weathering.

HYDROGEOLOGY

Hydrogeological sketch. The karsted limestone block of Nagykőmázsa Hill is morphologically well delimited from its surroundings. From the hydrogeological (respectively hydrological) point of view, however, it does not represent an independent unit; it is a part of the Bükk Mountains karst.

Borehole V—7, situated at the very centre of the exploration area, started at a height of 364,83 m a. s. l., taking into account the 122,0 m a. s. l. source level of the cold springs at Miskolctapolca, has been deepened to 250,0 m (114,83 m a. s. l.). It has reached, in fact, tha karst water table, and it has been built out into a water table observation well (design VITUKI). The VITUKI carried out water level measurements every week from February 1968 till December 1968, observing a fluctuation ranging from 124,0 to 130,0 m a. s. l.

The other drillings traversed the descending karst only. Even the deepest point of the exploration area is above the karst water table. So there are no springs at all in this area.

It turned out — according to the results of the connection testing by salt addition — that the karst water of the region is in direct communication with that of the Miskolctapolca springs.

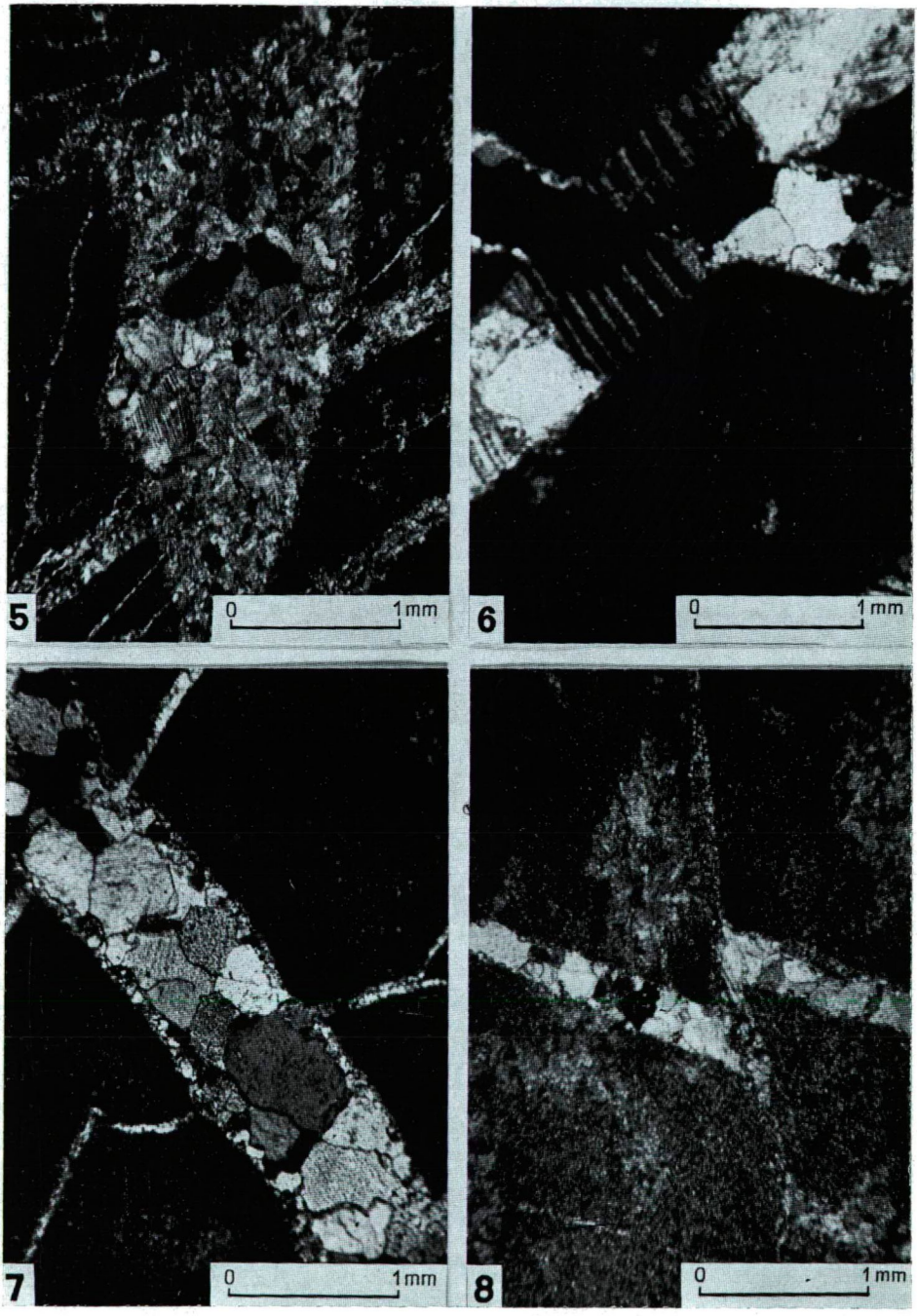
Karst phenomena. As for surface karst phenomena, strike-oriented lapies and smaller karrenfelden as well as two bigger and one smaller dolinas *(Fig. 1)* are characteristic.

Subsurface karstification is evidenced by cavities detected by means of radioactive logging in boreholes, along with clayey fillings and kataclastic intervals.

Traces of hot springs. In the quarry, during the course of exploitation, spheric niches of hot spring cavities (along faults), 1—2 cm to 1 m thick calcite veins are found. Materials testing adds other evidences (hydrothermally decomposed limestone, calcite, quartz, kaoline).

Nagykőmázsa Hill lies 2 km to the West from the hot spring area of Miskolctapolca and the nearby marked traces of hot spring activity in the abandoned limestone quarries of Várhegy Hill. Taking into account that both in the Várhegy exposures and on Nagykőmázsa Hill the above mentioned traces (cavities, calcite veins), which occur up to the summit, are oriented NE—SW, they can be considered as earlier source sites of the actual Miskolctapolca hot spring, or of a larger spring system.

Phot. 5. Thin section of the Ladinian limestone from 60,0 m of borehole III—5
Phot. 6. Thin section of the Ladinian limestone from 57,7 m of borehole VII—5
Phot. 7. Thin section of the limestone sample from 57,7 m of borehole VII—5
Phot. 8. Thin section of the limestone sample from 35,0 m of borehole VII—9



Phot. 5—8.

The hydrothermal activity ended with the Pleistocene uplift of the SW Bükk Mountains: sooner on the more elevated Nagykőmázsa Hill (384 m a. s. l.) and somewhat later on the lower Várhegy Hill (222 m a. s. l.).

The actual hot spring of Miskolctapolca, together with some cold springs, is ascending along faults delimiting the east side of Várhegy Hill *(Fig. 5)*. Also the inactive spheric niches of the hot spring cavities to be seen in the Cave Bains testify to rather recent uplift, suggesting the possibility of discovering hot water at more considerable depths, in the area characterized by the presence of this of hot spring caves.

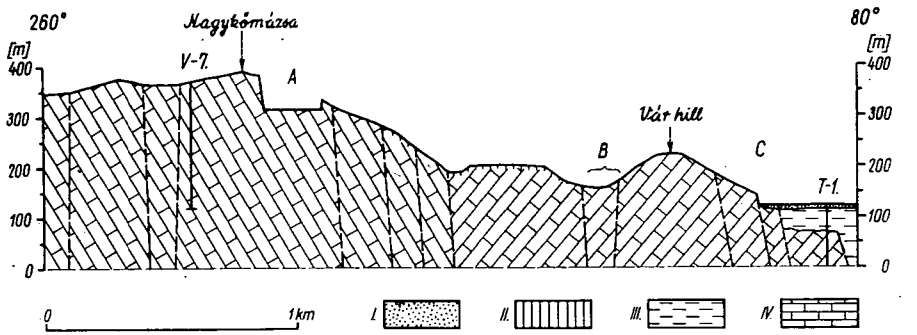


Fig. 5. General geological section across the Nagykőmázsa limestone exploration and Miskolctapolca spring areas. I. alluvium (Holocene), II. clay (Pleistocene), III. sand, clay, sandstone, gravel, brown coal (Helvetian-Tortonian), IV. limestone (Ladinian). *A* Nagykőmázsa limestone quarry; *B* Várhegy quarries; *C* Tapolca springs.

As a matter of fact, these caves are indicative of springs with higher temperature than that of the actual hot spring of Miskolctapolca (26—30 °C). Decrease in temperature is due to the uplift of the sediments of the SW Bükk Mountains, the displacement of resurgence sites and the cooling effect of cold water karst springs ascending along the same fault system, respectively.

REFERENCES

Balogh, K. [1964]: A Bükkhegység földtani képződményei. (Die geologischen Bildungen des Bükk-Gebirges.) A Magyar Állami Földtani Intézet Évkönyve *XLVIII*, 241—719. Budapest.

Csókás, J., Egerszegi, P., Vitális, Gy. [1970]: Geoelektromos mérések a miskolctapolcai Nagykőmázsán. (Geoelectrical survey in the Nagykőmázsa limestone quarry at Miskolctapolca.) Geofizikai Közlemények *XIX*, 33—40.

Hegyi-Pakó, J. [1970]: Hidrotermális hatások vizsgálata a miskolctapolcai Nagykőmázsán. (Untersuchung der hydrothermalen Einflüsse am Berg Nagykőmázsa bei Miskolctapolca.) Hidrológiai Tájékoztató (at press).

Láng, S., Miháltz-Faragó, M., Vitális, Gy. [1970]: A miskolctapolcai Nagykőmázsa dolináinak morfológiai és földtani vizsgálata. (Étude morphologique et géologique des dolines de Nagykőmázsa à Miskolctapolca.) Földrajzi Értesítő *XIX*. 77—85.

Papp, F. [1957]:Az ásvány- és gyógyvizek hidrogeológiája és fürdőtani leírása. (Hydrogeology and balneological description of the mineral and medicinal waters.) In: „Magyarország ásvány- és gyógyvizei." Ed.: Schulhof, O. Akadémiai Kiadó, 15—334. Budapest.

SCHMIDT, E. R. *et al.* [1962]: Vázlatok és tanulmányok Magyarország vízföldtani atlaszához. (Sketches and Studies to the Hydrogeological Atlas of Hungary.) A Magyar Állami Földtani Intézet alkalmi kiadványa, Műszaki Könyvkiadó, 1—664. Budapest.

SCHRÉTER, Z. [1954]: A Bükkhegység régi tömegének földtani és vízföldtani viszonyai. Hidrológiai Közlöny 34. 287—294. and 369—381.

VITÁLIS, GY. [1970]: Földtani és vízföldtani megfigyelések a miskolctapolcai Nagykőmázsán. (Geologische und hydrogeologische Beobachtungen des Berges Nagykőmázsa bei Miskolctapolca.) Hidrológiai Közlöny *50*, 49—55.

DR. GYÖRGY VITÁLIS
MRS. J. HEGYI-PAKÓ
Central Research and Design
Institute for Silicate Industry
Bihari u. 6.
Budapest X. Hungary

BOOK REVIEW

K. I. Sztrókay, Gy. Grasselly, E. Nemecz, J. Kiss:

Ásványtani praktikum II. (Mineralogical Practice. Volume II.)

Tankönyvkiadó, Budapest, 1970. 497 pages, 262 figures.

The Mineralogical Practice wants to help and promote the mineralogical instruction going on at the Universities from the practical aspects, too. The second volume appeared earlier than the first one.

The intention of the second volume is to acquaint physical and physico-chemical procedures and instruments generally and regularly used for the determination of minerals.

The arrangement of the material principally is systematized according to the examinational branches depending on the properties of mineral substances, within this we get a description of the certain methods in the order of the work. A summary of the field of application, the limits and restrictions of possibilities are added to every chapter. If only to small extent, we can obtain an insight into the historical antecendents of the development of the respective methods. From first to last the authors adhere to the didactical requirements, therefore after the explanation of the principles of some research methods they sketch the working and manipulation of the apparatus. This part is followed by practice in form of lessons, being never simple recapitulations, but further additions based on the preceding studies. Furthermore, we are provided a particular direction about the preparation of minerals for special examination or analyses and about the most important techniques. We do not say that after studying the book, everybody would perform all methods in the mineral determination, but it is a fact that this manual perfectly meets the most significant problems of instrumental determinative mineralogy.

The volume contains the following main chapters:

Thermal Investigation. This part treats the method of differential thermal, thermal gravimetrical and differential thermal gravimetrical analyses. The principles of the phase equilibrium diagrams were placed here too — in the nature of reason — as a physico-chemical study of the mineral genesis caused by thermal effect.

Optical Investigations of Transparent Minerals. We can follow the main steps of mineral identification by way of the polarizing microscope and its additional equipments through, in the form of description and working thirty-

three lessons up. The author concentrates on the use of the refractometers and the universal stage, too.

Investigation of Opaque Minerals. The chapter is divided into two parts: investigations by the ore microscope and determination of ore minerals by surface analysing methods.

The first part gives searching knowledge about the function and treating of the ore microscope, and lots of examples and lessons make it easy to understand the informations; they also find place to describe the most important technical works of ore sections.

The second part shows the simple *surface etching method* and the *print (contact and electrographical) method* demonstrated by numerous examples based on the most frequent metallic elements and ore minerals.

X-ray Analysis of Minerals. The relatively large extent of this chapter may be justified by the rapid development and widespread application of the method nowadays. Therefore this part explains the fundamental principles and geometry of X-ray diffraction. At the same time the author treats very carefully the practical application of the procedures: gives detailed information about the recording of powdered patterns and about identification of the diagrams.

The usefulness of the book is increased by the great amount of well selected text figures, numerous tables, microscopic photos and a few coloured insets.

We can state, that the volume is not only an excellent textbook for students, but it will become a valuable manual of the young geologists, too.

Dr. Cs. Ravasz,
Institute of Mineralogy, Geochemistry and Petrography, Attila József University
Táncsics. M. u. 2. Szeged, Hungary

LETTERS OF THE WORKING GROUP ON MANGANESE FORMATION OF INTERNATIONAL ASSOCIATION ON THE GENESIS OF ORE DEPOSITS

REPORT

ON THE STATUTORY MEETING OF THE WORKING GROUP ON MANGANESE FORMATION HELD ON 31 AUGUST 1970 IN KYOTO, DURING THE IMA–IAGOD MEETINGS '70

Participants of the Statutory Meeting:

DR. MICHAEL FLEISCHER (USA), PROF. DR. GY. GRASSELLY (Hungary), Provisional President of the Working Group, PROF. DR. H. HARDER (German Federative Republic), DR. A. KATO (Japan), DR. G. KAUTSKY (Sweden), Councilor of the IAGOD, PROF. DR. S. J. KIM (South Korea), PROF. DR. K. KRAUSKOPF (USA), PROF. DR. C. NAGANNA (India), PROF. DR. M. NAMBU (Japan), PROF. DR. M. VANEČEK (ČSSR), Secretary General of the IAGOD, DR. I. M. VARENTSOV (USSR), Provisional Secretary of the Working Group.

PROF. DR. GY. GRASSELLY, *Chairman:*

Gentlemen, Members of the Working Group,

First of all I should like to greet you all as the Provisional President of the Working Group on Manganese Formation. At the same time I should like to express my sincerest convinction that our work will prove to be fruitful not only as regards the present Statutory Meeting but in the future, too. I am sure of this since all of you, having taken part in the work of the Working Group, or willing to participate in the future, share a common interest in the problem of formation of manganese ore deposits and in the long series of geological, mineralogical and geochemical issues concerning the main question. And I may add to all this the numerous questions in the field of experimental methods and their application.

I am sure that we shall work together in a very useful way and this common striving will bring its results.

Please, take an active part in the activity of our Working Group. Hereby I open our Statutory Meeting.

DR. I. M. VARENTSOV, *Provisional Secretary:*

Mr. President, Members of the Working Group,

Let me express on behalf of the Soviet geologists, studying manganese ores, the deep gratification in connection with the organisation of Working Group on Manganese Formation. It refers as well to the Organising Committee

of the 7th Session of IMA—IAGOD, that gives us the necessary facilities to hold the meetings of this Working Group. Thus we are most thankful to the organisers of the 7th Session of IMA—IAGOD namely the Chairman of Organising Committee PROF. DR. T. WATANABE, General Secretary DR. I. SUNAGAWA, Chairman of Programme Committee PROF. DR. P. SADANAGA and our Japanese colleagues co-chairing the meetings of the Manganese Group — PROF. DR. M. NAMBU and DR. A. KATO.

To this audience there is no necessity to stress on the importance of researches of various aspects of geology, mineralogy and geochemistry of manganese ores. Instead of this I would like to point out some aspects of the activity of WGMF.

The main points of the future activity of WGMF are shown in the Provisional Programme, which we are going to discuss, try to improve, and accept if you have no serious objections. Now it seems rather reasonable to stress the PRELIMINARY character of this Programme and the need to make corrections. Certainly, we take into consideration all the remarks received by PROF. DR. GY. GRASSELLY and by me for the year gone. And these amendments should contain the results of tonight's discussion.

However, some problems I think, are rather essential and let me draw your attention to them.

Manganese ores today may be regarded as well studied, in comparison with ores of other metals. However, there are some serious problems which have been tackled for the last 20—30 years in a very limited way. On the other hand, the advances in solving some geological and geochemical problems have been followed by new more complicated ones, which may be solved by applying the recent achievments of science and technology.

These problems may be divided into two groups:

a) Structural-Geological,

b) Mineralogical-Geochemical.

In manganese geology we are still seriously interested in the problems of structural, formational and facies control of localization of manganese deposits. Their relation to certain stages in the development of structural regions are worthy of investigation. The volcano-sedimentary Mn deposits are of special interest. I mean, their localization formational development in the general magmatic history of the region. However, in the last few years some works, concerning narrow, regional subjects have been published. But unfortunately the problem of manganese-bearing jaspilite formations were still out of attention of research-geologists. The prominence of this problem is obvious — this is an example to study the relation of manganese — and iron — ore forming processes in Precambrian.

In manganese mineralogy of recent times there has been no essential progress. There are lots of uncertain points in the matter of characterisation and systematization of information on manganese oxide minerals. It is not evident for me why the systematical publications on manganese oxide minerals that were so successfully carried out by American authors in the forties and fifties is now discontinued. Now in spite of the great number of papers, a compiled work is not published, which summarizes all the information on manganese especially oxides, compounds and their structures. Let me explain it by an example. We don't know as a matter of fact what is BIRNESSIT, the mineral whose abundance may be compared in certain sense with quartz.

In the problems of manganese geochemistry, probably, the fundamental features of ore formation of this element are focussed. Unfortunately, for the last 30 years, since V. I. VERNADSKIY put on several problems, we have not done much. Despite the evident biogenic role of manganese in the upper part of the lithosphere and hydrosphere, we still have no concrete information on these questions. I will give you only two examples: still there are not works showing the role of Mn-oxidizing, -reducing microorganisms, and the mechanism of this process. In waters of recent basins where colossal amounts of manganese and associated elements are accumulated, the form of presence of this element is not still known. Certainly the problem of the chelate-like compounds, the components of proteins, amino-acids, as the probable form of Mn in sea water are still waiting to be solved.

The explorer studying the geochemistry of manganese tries to find out the past processes on the ground of ancient, altered products. This task may be better solved, dealing with the modern processes of manganese ore formation in lakes, seas, oceans and in thermal springs of volcanic zones, because we can perform the direct measurements of the characteristics of this events.

The investigations of the kinetics and mechanism of manganese ore formation processes are of no less significance.

I may point out three approaches to solve this very complicated problem — study of manganese ore formation process.

a) Theoretical, calculated one, based on thermodynamical characteristics, which adequately correspond to natural processes.

b) The method of experiments, modelling the processes or of some of their stages.

c) Direct observation of modern natural process, measuring all the available characteristics.

I restrict myself only to some parts of the problems, that seems to me essential. Of course there are much more.

Looking for an approach to solve these problems PROF. GY. GRASSELLY and I have drawn up this programme. I hope it is obvious, that along with the exchanges of current results — I mean regular meetings of WGMF and preparing the 2nd International Symposium on Manganese Ores, it is necessary to summarize the results of investigations already accomplished. I concern the preparation of materials for an International Monograph on Manganese Ores. Finally, it would be good to have similar views on some features of composition and texture of manganese ores and minerals. For this purpose it is reasonable to arrange the wide exchange of standard collections.

My Soviet colleagues supported this Programme. Many of them would like to take part in carrying out some sections of it. We clearly understand all the difficulties, that might arise on the way of its realization. However, the problems of investigation of manganese ores, I believe, are so significant that they deserve any expenses of our force, energy, and time.

The path of scientific progress has always been paved at the expense of uneasy efforts. I am sure, by following the programme I have proposed, in a short time, more explorers can take part in solving these problems and their research contacts will be more closer.

PROF. DR. GYULA GRASSELLY, *Chairman:*

Gentlemen,

Now turning to the discussion of items of the Programme of the Statutory Meeting having been sent to each national representative in due time, the first question is the *necessity and possibility of organizing the 2nd International Symposium on Manganese.*

At first sight it appeared likely to try to organize it during the 24th International Geological Congress in Montreal, Canada, and this idea has been embodied in the Provisional Programme published in Acta Mineralogica-Petrographica Universitatis Szegediensis Tom. XIX/1, in 1969. Since, however, our Working Group has just been formed, the question arises, whether we have strength and what is more, time, to organize in 1972 (and regarding the deadline of submitting papers even earlier) a real international symposium with a wide range, depth and on a level that would prove to be a good continuation of the symposium held during the International Geological Congress in Mexiko. This problem has been touched by our colleagues in the U. S. A. and in agreement wit them I see the following possibilities:

a) Our WG could hold a Scientific Session during the 24th International Geological Congress, for which even the colleagues in the USA can submit several lectures — since due to the short time they could not actively participate in the present session.

b) Regarding the results of the present Statutory Meeting and Scientific Session consider the proposals of our American colleagues to organize a really world-wide Second International Symposium on Manganese during the 25th International Geological Congress.

c) If you agree with the above two possibilities, we shall ask the IAGOD Council to arrange with the Organizing Committee of the 24th International Geological Congress (MR. JOHN E. ARMSTRONG, Secretary General, 601 Booth Street, Ottawa, Canada) to secure place and time for the Second Scientific Session of our Working Group, and we must encounter what topics and how many lectures from the different countries could be expected for this session, so that the Secretary General of the Organizing Committee of the Congress could be informed of that in due time. Moreover, we must ask the IAGOD Council to pass a decision concerning our proposal under *b)* and give help for its realization.

Resolution: The proposal on organizing the Second International Symposium on Manganese was discussed and the members decided that during the 24th International Geological Congress in Montreal a Scientific Meeting of the Working Group on Manganese Formation is to be held with about 20 lectures concerning the different fields of manganese researches and the Second International Symposium on Manganese could be planned from now and may be held during the 25th International Geological Congress. National representatives are requested to submit the titles of their and their compatriots' lectures to be read at the scientific session during the Geological Congress in Montreal as soon as possible, to the address of MR. JOHN E. ARMSTRONG (see above).

The next item of our programme: *providing a systematic information on the activity of the Working Group.*

I think that regular information on the activity of the Working Group and at least annual reviews of the most important results in manganese ore researches reached in different countries would be very useful. In this respect I would suggest the following. The Institute of Mineralogy, Geochemistry and Petrography of the University of Szeged (Hungary) has an annual publication — *Acta Mineralogica-Petrographica* —. The language of publications is English and the topics are mineralogy, geochemistry and petrography, geology. In the course of the twenty five years of its publication this Acta has become fairly well known all over the world and the papers published in it are regularly reviewed by the Chemical Abstract, the Mineralogical Magazine and by the Zentralblatt für Mineralogie.

The Acta Mineralogica-Petrographica so far has not been on a commercial basis: we are sending it to institutions and even to single persons on an exchange basis. For information I mention that 300 copies are sent to different countries among them 30—30 copies to the German Federative Republic, the Soviet Union and the United States etc.

As the Editor of this Acta Mineralogica-Petrographica I am ready to publish annual reviews written by the respective national representatives summarizing the more important results in manganese ore researches in their own countries. Of course, your papers sent for publication in our Acta are welcomed as well.

It is my duty, however, to inform you that MR. DORR, national representative of the USA informed me on the opinion that this Acta is not known well enough in the States or e. g. in Africa to fulfill this duty — namely to be a source of information for people interested in manganese ore researches. They think that either *Economic Geology* or *Mineralium Deposita* or *Geochimica et Cosmochimica Acta* would be more suitable for this. I can but agree with them in this respect, since it is obvious that a university publication cannot compete in volume, number of copies, etc. with these international journals.

To decide the problem of solving the question of information — either Acta Mineralogica would be the organ, as suggested by me, or to accept Mr. Dorr's suggestion — is now your task. On my part I should mention that if the national representatives supply me with the list of institutions, where they think our Acta is necessary to be sent, I can promise that in due time they will receive it.

I should also like to emphasize that Acta Mineralogica would publish first of all reviews of results of researches in particular countries written by the questioned national representatives themselves.

Resolution: The question of accepting a journal as a semi-official organ of the Working Group on Manganese Formation was discussed in details, and decided to request the University of Szeged (Hungary) to permit to have the Acta Mineralogica-Petrographica as semi-official publication of the Working Group. PROFESSOR GY. GRASSELLY, Editor of Acta Mineralogica-Petrographica assured the Working Group on behalf of the University to make available 20—25 pages in the Acta for the use of the Working Group.

I believe that you agree with the next item on our agenda: I think it would be very reasonable to make an *exchange of samples of typical standards of manganese ore deposits* from the more important mines of different countries. If such a demand really exists, I am convinced it could be met with the help of the national representatives.

> **Resolution:** The question of exchange of standard minerals and ore samples was discussed and decided to request all national representatives to undertake an active role in the future in order to realize this aim. To this end all the national representatives will receive a list of the names and addresses of those having already taken part in this work, and any further information can be obtained by the respective national representative. As a matter of fact, the exchange of standard minerals and ore samples lays on the basis of mutuality.

As a farther and further aim, we can concentrate our efforts on compiling by an international panel of experts a *monography*, where — following the suggestions given by you and the national representatives — the chapters are written by the most competent researchers or research-groups. I know that at the present time our Working Group is not strong enough to start such an enormous work in the hope of success and up to a very short deadline, but I think that to consider this suggestion is not early even today. If you are of the opinion that a monography as outlined in the Provisional Programme is really necessary, as a first step, we can start upon forming the list of topics touched upon there and to form the personnel of the Editorial Board. This is a problem to be undertaken only by a wide circle of experts, naturally asking for the opinion of our colleagues, who are interested is manganese ore researches, but could not participate in the present session.

> **Resolution:** National representatives are requested that taking into consideration remarks of researchers working in their respective countries, they draw up a proposal on the tematics of the mentioned monography chapter by chapter and furthermore to suggest names of desired authors for the particular chapters. They are further requested to submit these suggestions in 1971 to the President or Secretary of WGMF so that all the national representatives could receive them in mimeographed form. Suggestions will be discussed and work started during the Business Meeting to be held at the time of the 24th International Geological Congress in Montreal.

And concerning the last point of our Provisional Programme, I think, *we must strive to include into the activity of our group all those interested in manganese ore researches, experienced scientists as well as promising young researchers.* If we could gather all people interested in this very wide and manyfold field and could inform our members regularly on the activity and aims and results of the Working Group, this would promote a closer connection, exchange of ideas and publications and materials, too. Moreover, if as it has been proposed, we shall be able to give a detailed information regularly, of the newest scientific results attained in different countries, this means a considerable step forward in performing the aims of our Working Group.

Of course, the bulk of work will be done in all this by the national representatives of the participating countries.

As a result of last year's correspondence up to this time the following countries are represented in the activity of the Working Group: Bulgaria, Czechoslovakia, Hungary, India, Jugoslavia, the Soviet Union, the United States of America. I should like to express my sincerest gratitude from here as well to the national representatives of India, the Soviet Union and the United States, namely to DR. SUPRIYA ROY, DR. IGOR M. VARENTSOV and DR. JOHN VAN N. DORR for their helpful assistance, owing to what our work could at all be started, and also to thank our Japanese friends for their excellent and careful work done in organizing our meeting. It is their merit that we can sit here, holding our Statutory Meeting and first Scientific Session.

Names of *national representatives* participating in our work can be found in the last issue of Acta Mineralogica-Petrographica (1969). Considering recent correspondence and personal exchanges of views, I would ask you, Gentlemen, to reinforce these national representatives and accept the following names for this office:

United Arab Republic: PROF. DR. E. M. EL SHAZLY (Cairo, Egypt);

South Korea: PROF. DR. SOO JIN KIM (Seoul, Korea);

Japan: PROF. DR. MATSUO NAMBU (Sendai, Japan);

Roumania: PROF. DR. R. DIMITRESCU (Bucureşti, Roumania).

The Geological Institute of Marocco expressed an interest in the work, although no name of a national representative was proposed from there. The representation of the Federative German Republic will soon be arranged by correspondence.

> **Resolution:** The Working Group accepts the proposals and wishes success to the former and newly elected representatives in their work for the purposes of the Working Group. National Representatives are requested to fill in an Application Form for Membership and send it to the Organizing Secretary (PROF. DR. P. ZUFFARDI, Cagliari, Sardinia, Italy) of the International Association on the Genesis of Ore Deposit — in the case if they are not members yet.

Now I ask PROFESSOR M. VANEČEK, Secretary General of IAGOD, to put forward the proposal of the Council of the IAGOD to elect the new officials of the Working Group for the next four-year period.

PROFESSOR M. VANEČEK, *Secretary General of the IAGOD:*

Mr. Chairman, Members of the Working Group,

I have been honored with the task to interpret to you the proposals of the IAGOD Council: to elect for the next four-year period PROF. DR. GY. GRASSELLY (Hungary) President of the Working Group, PROF. DR. C. NAGANNA (India) and DR. JOHN VAN N. DORR (USA) Vice-Presidents; DR. I. M. VARENTSOV (USSR) Secretary. At the same time on behalf of the IAGOD Council I wish you success in your future work and I express my best personal wishes as well.

Resolution: The Working Group accepts the IAGOD Council's proposals and unequivocally elects the following officers:

President: PROF. DR. GY. GRASSELLY (Táncsics M. u. 2., Szeged, Hungary)
Vice-Presidents: PROF. DR. C. NAGANNA (Dept. of Geology, Bangalore University, Bangalore–1, India)
DR. JOHN VAN N. DORR II, (US Geol. Survey, Building 10, Washington, D. C. 20 242)
Secretary: DR. IGOR M. VARENTSOV (Pyzhevskiy Pereulok 7, Moscow, Zh–17, USSR).

PROF. DR. GY. GRASSELLY, *President of the Working Group:*

Gentlemen, Members of the WGMF,

Permit me in the name of the newly elected officials to express my sincerest gratitude for your kind support and promise our willingness to serve and promote the work of our Working Group in the future according to our best knowledge. Thank you for your participation and for the many useful suggestions. I will inform the IAGOD Council about what has been done here and all the resolutions. I wish you good work and results in the future. I close this Statutory Meeting.

DR. I. M. VARENTSOV,
Secretary of the Working Group
on Manganese Formation of the IAGOD
Pyzhevskiy pereulok 7, Moscow Zh—17,
USSR

PROF. DR. GY. GRASSELLY,
President of the Working Group
on Manganese Formation of the IAGOD
Táncsics M. u. 2., Szeged, Hungary

LETTERS OF THE WORKING GROUP ON MANGANESE FORMATION OF INTERNATIONAL ASSOCIATION ON THE GENESIS OF ORE DEPOSITS

REPORT

ON THE FIRST SCIENTIFIC MEETING OF THE WORKING GROUP ON MANGANESE FORMATION, HELD ON 1ST SEPTEMBER 1970, IN KYOTO INTERNATIONAL CONFERENCE HALL, KYOTO, JAPAN

Chairman: GY. GRASSELLY.
Co-Chairmen: M. NAMBU and A. KATO.

Programme of the Scientific Meeting:

Some Problems and Trends in Manganese Ore Researches. An Introductory Talk. By GY. GRASSELLY.

Zonal Arrangement of Minerals at the Granitic Contact with the Manganese Ore Deposit in Nodatamagawa Mine, Iwate Prefecture, Northern Japan. By M. YOSHII and T. KOMURA.

Origin of the Manganese Ore Deposits of Mysore State, India. By C. NAGANNA.

Manganese Minerals from Janggun Manganese Mine, Korea. By SOO JIN KIM.

Jurassic Manganese Ores of Hungary. By J. CSEH NÉMETH, GY. GRASSELLY, E. NEMECZ and Z. SZABÓ.

On the Leaching of Manganese Produced by the Interaction of Basic Volcanic Materials with Sea Water. By I. M. VARENTSOV.

Role of Manganese Minerals in the Migration of Elements. By GY. GRASSELLY and M. HETÉNYI.

The lectures submitted for the present scientific session can be divided into two groups. Lectures of the first group are dealing with geological, genetical problems of particular manganese deposits and the second group comprises lectures devoted to dissolution, migration, accumulation of manganese and to problems of adsorption properties of manganese compounds.

GY. GRASSELLY in his Introductory Talk gives a special stress to the complexity of the problems of manganese ore researches what involves the necessity of introducing methods of investigations having already been successfully applied in other fields as well as developing the already applied techniques. He mentions that although more and more, very accurate data are available thanks to up-to-date methods rendering great amount of information, the difficulties in being oriented in this amazing amount of information are also increasing. To overcome these and similar difficulties in the field of

manganese ore researches — as far as it is at its disposal — is one of the aims of the IAGOD WGMF, promoting the development of connections between researchers working in similar fields in different countries, mutual information or exchange of substances to be investigated.

The second part of the Introductory Talk, restricted by time, length and the field of interest of the author himself, shortly summarizes researches yielding very promising results lately in manganese ore researches, and in which fields further researches, model-experiments can bring further result as well. The importance of the pH and the redox potential is especially emphasized by the author. Not less promising field — according to the author — is the study of genetical correlations between conditions of formation, the formed manganese compounds (modification) and the minor element content. Perhaps similarly important is for the metamorphism the study of thermal stability conditions of different manganese compounds and conditions of their transformation.

In connection with model-experiments it is to be emphasized that these methods can only bring results when the experiments are not far from reality, are not alienated from nature but the laboratory results compared constantly with reality step by step are giving deeper and deeper insight to connections hidden in the very self of processes.

An interesting picture of the zonal arrangement of minerals found on the granite contact of manganese ore in Nodatamagawa mine is described by M. YOSHII, and T. KOMURA. Their information is even more interesting, since — as they write — a sharp contact between manganese site and granite intrusion as experienced here, is rather rare. After a description of the three zones — mostly based upon optical methods and illustrated by photos — they outline their theory of the process of formation of contact minerals. Characteristic minerals of Zone 1: quartz, dannemorite, spessartine; of Zone 2: alkali feldspar, dannemorite, quartz, pyrophanite and apatite; of Zone 3: plagioclase, biotite, dannemorite, hornblende, potassium feldspar, manganese-bearing pyroxene, quartz and apatite. As the authors describe, the amount of Mn continuosly decreases from Zone 1 towards Zone 3. As the authors write, upon the effect of grandiorite intrusion the whole site suffered thermal metamorphism and the originally supposed carbonate and oxide manganese ores had been recrystallized into silicates and other minerals — in the contact zone mostly into rhodonite.

C. NAGANNA in his paper deals with the origin of manganese deposits in Mysore State, India. Series of explorations carried out for years together with his co-workers brought him to suppose the syngenetic origin of manganese ore sites in Mysore State — the old Fermor-division called it "lateritoide manganese ore" — and these ores have been described in a similar manner by several other authors. This paper well illustrates that older, widely accepted statements can be modified, corrrected, our knowledge widened by manysided experiments carried out upon a unique conception, based upon great amount of data and comparing different deposits. Besides textural differences there are also variations in the mineral distribution and occurrence in depth of ore types distinguished by the author, and all these reasons justify the differentiation of the types. The syngenetic origin is very successfully proved by the author on analyzing the manganese formation and host rocks relation. It would be very useful if the author and his co-workers find possibility in the future

to investigate the correlations between the distribution of ore types and minor element content.

Soo Jin Kim in his paper describing manganese ores of the Janggun mine in Korea makes use in the study of manganese minerals formed by supergene oxidation of manganese carbonate of the possibilities rendered by the most diverse methods of investigations and describes three trends of supergene minerals.

A paper by J. Cseh Németh *et al.* deals with geological relations of Jurassic sedimentary manganese ore deposits in Hungary, and makes comparison between the two most important mines, Úrkút and Eplény. According to the authors the main amount of manganese was accumulated in the Liassic in the sedimentary basin as finely layered chemical sediment. Different oxide minerals — mostly cryptomelane, pyrolusite and in the oxide-carbonate transitional zone greater amount of manganite — were formed by oxidation of the carbonate. Besides, in some places, primarily deposited oxide minerals can also be considered. According to the authors moving away from the carbonate-oxide transitional zone some territorial distribution can be found, the amount of minerals of greater oxidation state is increasing.

I. M. Varentsov in his lecture treats the interaction of the basic volcanic substance and sea water and by model experiments he gives a picture of the extent of the leaching of manganese, at the same time investigating the dissolution of Fe, SiO_2 and P. In the discussion it is very interesting that he compares the extent of Mn and SiO_2 leaching zones and concludes that in the case of some granules the depth of zone where the leaching of Mn takes place is 7—15 times greater than the leaching zone of SiO_2. Besides several other factors, by all probability, the differences in the mobility of some components play an important in this. The model experiments and calculations support the view that although the origin of total excess pelagic manganese cannot be interpreted by leaching basaltic rocks only, it is a fact that a considerable amount of manganese can be dissolved from the lavas. I suppose that very interesting results could be obtained by repeating the above model experiments in artificial sea water aerated to different extent, or in sea water with different CO_2 content and at the same time, measuring the changes in the concentration of the solution as well as those in the redox potential.

Gy. Grasselly and M. Hetényi in a paper study the adsorption ability of natural and artificial manganese compounds towards different ions and point out on the one hand the role of factors influencing adsorption and on the other emphasize that these adsportion processes of not exclusively but at least partly are responsible for the sometimes very remarkable minor element content of different manganese deposits. One point of the work requires some amendment, since authors after submitting the manusript carried out additional measurements, and the IR spectra of cryptomelane samples untreated and treated by Pb-salt solution exhibited some differences what confirms that in the case of Pb adsorption we are having a chemosorption. A further suggested step would be to make clear by experiments the sometimes very remarkable difference between the adsorbed amount of Co and Ni.

Prof. Dr. Gyula Grasselly,
Chairman of the Scientific Meeting
of the Working Group on Manganese
Formation of the IAGOD

LETTERS OF THE WORKING GROUP ON MANGANESE FORMATION OF INTERNATIONAL ASSOCIATION ON THE GENESIS OF ORE DEPOSITS

REPORT

ON INTERNATIONAL SYMPOSIUM ON THE GEOLOGY AND GENESIS OF PRECAMBRIAN IRON AND MANGANESE FORMATIONS, KIEV, AUGUST, 19—25, 1970

JOHN VAN N. DORR, II

A symposium on the geology and genesis of Precambrian iron and manganese formations was held in Kiev, Ukranian SSR, in August 1970, under the auspices of UNESCO, the Ukranian Academy of Sciences, and the International Association of Geochemistry and Cosmochemistry. Papers were read and discussed in Kiev from August 20 to 25; most of the geologists attending the symposium thereafter went to Krivoi Rog to visit and observe the great iron ore deposits and complex structure and stratigraphy of that area. The organization of the symposium was most effectively handled by Academician N. P. SEMENENKO of the Academy of Sciences of the Ukranian SSR and his colleagues in the geological, geochemical, and geophysical community of the Ukranian SSR. Hospitality was warm and generous. Scientific communications from the western world were organized by PROF. EARL INGERSON, President of the International Association of Geochemistry and Cosmochemistry. Funds for travel to Kiev were supplied by UNESCO.

I was requested by PROF. GYULA GRASSELLY, President of the Working Group for Manganese of the International Association on the Genesis of Ore Deposits, to summarize the results of the Symposium with respect to manganese geology. The papers will be published in full in a volume of proceedings by UNESCO; inevitable delays in publication make such a summary desirable.

Most of the attention of the Symposium was perforce focussed on iron-formation and ore deposits. A number of interesting papers were read on several of the major manganese deposits of the world, however, and new information on geology and genesis was presented. In particular, papers on the Moanda deposits in Gabon, the Serra do Navio deposits of Amapá, Brazil, Moroccan deposits, Africa, and the deposits in Madhya Pradesh and Maharashtra, India, as well as a paper discussing the relations between iron- and manganese-formations in Brazil and Bolivia were of interest to manganese specialists.

PROF. FRANCIS WEBER of the University of Strasbourg described the manganese deposits in Gabon, which include the Moanda, the largest high-grade deposit of manganese oxide yet discovered in the world; he presented new information which clears away certain past misconceptions concerning the

genesis of this great deposit. WEBER, who has worked for many years on this problem, showed that the oxide ores were derived by the weathering and oxidation of a zone of carbonate rock in the unmetamorphosed Francevillian (deposited about 1740 m. y. ago) of Gabon. This zone, revealed by drilling in a downfaulted block to be about 75 meters thick, averages about 13 percent Mn as carbonate; the original rock was a carbonate-rich black shale, slightly pyritiferous and poor in detrital components. An average of ten samples of [illegible] lows (in percent): SiO_2, 23; Al_2O_3, 6.3; CaO, 8.6; MgO, 4.3; Na_2O, 0.13; K_2O, 1.3; TiO_2, 0.17; P, 0.14; Fe, 2.5; Mn, 15; loss on ignition, 29.1. Organic matter is said to average about 6 percent, and iron is present as pyrite. The manganese is present as a complex manganese-calcium-magnesium carbonate.

Near the margins of the sedimentary basin in which this manganiferous carbonate protore was deposited, the manganiferous zone immediately overlies a 10-meter zone of iron-formation. In this iron-formation three facies are present, the sulfide, the carbonate, and the silicate. These facies are intergradational. The manganese content of the iron-formation is only about 0.2 percent; the iron content is about 31 percent.

The ore of commercial grade underlies large plateaus, the largest of which are the Bangombe (19 km^2 of mineralized area) and the Okouma (13 km^2 of mineralized area). These plateaus are at about 600 meters altitude and represent the remains of an erosion surface that was formed at the end of the Cretaceous or in early Tertiary time. Run-of-mine ore contains about 44 percent Mn, 4.4 percent Fe, 8.2 percent Al_2O_3, and 7.0 SiO_2. The ore is washed and screened, and the grade of ore marketed is about 50 percent Mn. Reserves are in order of 200,000,000 tons of washed ore.

WEBER makes a masterful analysis of the processes involved in the derivation of the oxide ores from the carbonate protores, too long for summary here. The discussion of the ultimate origin of the manganese and iron of the Francevillian necessitated a paleographic study of the whole sedimentary basin in which these and other rocks were deposited. WEBER postulates a compound basin, in one part of which volcanic rocks were abundant, in the other part of which the iron- and manganese-rich rocks were deposited, but in which volcanics of the same or older age are not abundant. He believes that the iron and manganese were of volcanogene origin, but transported long distances before deposition. Two types of volcanism are represented in the Francevillian; an early spilitic volcanism contemporary with the manganiferous deposits, although more than 100 km away from the larger concentrations of manganese, and an ignimbritic volcanism younger than the manganiferous beds. Naturally the spilitic type is thought to be the source of the manganese and iron. The high organic content of the rocks and the fact that the iron is present as sulfide, carbonate, and silicate and the manganese as carbonate both indicate a low Eh environment, which would facilitate long transport of metallic ions before precipitation.

PROF. SUPRIYA ROY of Jadavpur University discussed, in a beautifully illustrated paper the Precambrian manganese formations of India with particular reference to the effects of metamorphism. He showed that the syngenetic manganese oxide beds of India are in specific stratigraphic zones and are intimately interbedded with manganese silicate rocks in pelitic schists, quartzites, and carbonate rocks. No contemporary volcanic rocks are known.

The metamorphic facies of the manganiferous rocks ranges from the greenschist through the almandine-amphibolite facies, as shown by the enclosing pelitic rocks. Local contact metamporhism to the hornblende-hornfels and pyroxene-hornfels facies has been observed. ROY traces in considerable detail the mineralogical and textural evolution of the manganese minerals through the different metamorphic facies and subfacies. He considers that braunite is the first metamorphic mineral to appear; the mineral is stable to the sillimanite-almandine-muscovite subfacies. Bixbyite appears in the quartz-albite-epidote-biotite subfacies in association with hollandite and braunite and continues in the quartz-albite-epidote-almandine subfacies. Hausmanite, jacobsite, and vredenburgite (two-phase intergrowth) appear in the staurolite-almandine subfacies, continuing to the sillimanite-almandine-muscovite subfacies in association with braunite and bixbyite. Textures change with degree of metamorphism, ranging from colloform and fine-grained oxides in low-grade facies to granoblastic in the higher facies. ROY relates the mineral assemblages of the manganese oxide ores in different grades of metamorphism to progressive reduction of original higher oxide phases with relatively great fo_2, above those values prevailing in analogous iron-bearing systems and above values in similar rhodochrosite-bearing assemblages.

G. CHOUBERT and A. FAURE-MURET of the Museum of Natural History, Paris, presented a paper summarizing the literature on the Precambrian manganese deposits of the Anti-Atlas of Morocco. These deposits are both stratiform and in thin veins; there has been considerable disagreement as to the origin of the stratiform deposits, none of which is very large. The stratiform deposits, of which the Idikel and Tiouine are the best known, are remarkable for the large content of lead and BaO, the lead ranging to more than 2 percent and the BaO to more than 20 percent. Copper minerals are associated with some of the deposits.

Although the Idikel deposit is in Precambrian II rocks, or middle Precambrian, and the Tiouine deposit in Precambrian III rocks, or upper Precambrian, both are associated with continental and lacustrine sandstone, shale, and conglomerate. Manganese is present at transitional phases between the rock types in thin to moderately thick beds of no great lateral persistance. The Idekil deposit has variously been attributed to hydrothermal syngenetic, sedimentary syngenetic, and hydrothermal epigenetic origin; the present authors took no stand. The Tiouine deposits have been attributed by BOULADON and JOURAVSKY to a hydrothermal syngenetic origin, the manganese having been introduced into a lake by hydrothermal solutions and there deposited. The present authors consider that the deposit is hydrothermal epigenetic, the manganese minerals having replaced preexisting sediments.

There are hundreds of small vein deposits in the Precambrian III volcanic rocks of the Ouarzazate region, all small and none persistent in depth. The maximum known depth is about 100 meters; most are much shallower. The longest vein is about 800 meters; most are much shorter. Thickness is measured in centimeters or, rarely, decimeters; some short veins having dolomite gangue may be a meter or two wide. The veins are clearly epithermal epigenetic deposits closely related to volcanism.

The authors stress that the reason for the close relation between the predominantly rhyolitic volcanism and the formation of these manganese deposits is

unknown. The rhyolites are very poor in MnO, and the vein deposits occur not only rhyolite but in other volcanic rocks and even in granite.

B. CHOUBERT discussed the manganese deposits in the Guianas and their relation to the fundamental structure of the shield area. With the exception of the Amapá deposits of Brazil, none of the deposits in the Guiana Shield have been economically successful, although the Matthews Ridge deposit in Guyana was worked for some years.

B. CHOUBERT points out that the Guiana Shield has two kinds of granites, one high in K_2O, the other, lower in K_2O, interposed between the high-potassium granites. The manganese deposits, which are all "gondite" deposits of ultimate sedimentary origin, are associated with the transition between the two types of granite, which CHOUBERT believes reflects the edges of ancient geosynclines. The manganese deposits are said to be associated with the volcanic sedimentary part of the old range between the geosynclines.

The "gondites" are present in thin lenticular beds in phyllite, quartzite, schist, and amphibolite of sedimentary origin. They are low in iron, containing one to two percent Fe, whereas the intercalated shale may contain as much as 10 percent Fe_2O_3, and some schists contain as much as 28 percent Fe. The "gondite" are everywhere associated with carbonaceous rock. The author states that there is no provable genetic relation between the ophiolitic rocks of the Guiana Shield and the manganese mineralization. He also states that there is no relation between the itabirite zones in the Guiana Shield and the occurrence of manganiferous zones.

The manganiferous zones are all thin, ranging to a meter or more in thickness, and consist of the common metamorphic manganese silicate minerals plus rhodochrosite in some deposits. These minerals have been oxidized to varying depths by supergene processes, and small low-grade deposits of the oxide minerals have formed. According to the author, the manganiferous zone at Matthews Ridge, the largest yet found in the Guianas proper, is some 30 km long (although not continuous) and 150–175 meters thick. It consists of thin layers of "gondite" alternating with barren rock consisting of chert lentils, carbonaceous phyllite, sandstone, and clays. Borings show impoverishment with depth; he states that in the first 30 meters the tenor declined from 40 to 12 percent Mn, and that enrichment ceased at the water table.

Three papers were presented on manganese deposits in Brazil. WILSON SCARPELLI, geologist and mine manager at the Serra do Navio mine, discussed the Serra do Navio manganese deposits on the south edge of the Guiana Shield, just north of the Amazon. This very important producing area has contributed more than ten millions of tons of high-grade ore to commerce, and reserves are substantial. The ores are weathering products of large lenses of rhodochrositic "gondite" intercalated into metasedimentary rocks of the Serra do Navio Group of the Amapá Series. The Serra do Navio Group overlies the Jornal Group, a thick, dominantly amphibolitic series of rocks of varying composition thought to be metasedimentary in origin.

The Serra do Navio Group consists of metasedimentary rocks deposited cyclically. They are divisible into three facies, quartzose, biotitic, and graphitic. Three cycles of deposition have been recognized. The quartzose facies is a metachert containing intercalations of calc-silicate and marble lenses. The biotite facies is a pelitic sediment now metamorphosed to a biotite schist with sillimanite, andalusite, and pink almandite. The graphite facies, which may

contain as much as 20 percent C, is a metamorphosed carbonaceous clay. The manganiferous lenses are in the graphitic facies.

SCARPELLI made a very interesting and useful statistical analysis of 421 contacts between the facies to determine their gradational or nongradational nature and the relations between the rock facies. The analysis permitted the elucidation of the stratigraphic sequence of these highly folded and metamorphosed rocks. The cycles start with chert at the bottom, followed by the pelitic rocks now in the biotite facies, followed by the carbonaceous clays with which the protore was deposited.

The sequence indicates that deposition started in an oxidizing environment having pH greater than 7.5. The environment moved toward lower pH and considerably lower Eh as the pelitic material accumulated first to form the rocks now in the biotite facies, and then to pelitic rocks with very high organic carbon content and manganese carbonate lenses. An abrupt change in the environment then resulted in a new cycle of high Eh and pH, to be repeated at least three times. SCARPELLI suggests that these cyclical changes in environment are best explained by changes that would be produced on a shallow marine platform involved with periodic epeirogenic subsidence; this model fits the lenticular nature of the sediments deposited and their compositional variation. Radiometric dating indicates that the latest of three metamorphisms suffered by these rocks took place about 1750 million years ago.

The "gondite", composed of the usual manganese silicates dominated by spessartite, is principally on the edges of the manganese carbonate lenses and along strike where the lenses disappear. The high-grade ore formed principally from the rhodochrosite lenses; "gondite" produces less, and lower-grade, oxide ore. SCARPELLI points out that the ore is in a continuous process of secondary enrichment, being dissolved at the surface and reprecipitated at depth and laterally from the main ore zone. Unlike the situation described by B. CHOUBERT, supergene enrichment has proceeded at least 20 meters below the level of the master stream in the Serra do Navio area, although the major ore deposits are related to high-level erosion surfaces.

PROF. EVARISTO RIBEIRO, JR., of the University of São Paulo, discussed jacobsites from the Urandi manganese district, Bahia, Brazil. In the Urandi district, ores formed by the weathering of two types of protore, carbonate and oxide. The jacobsite formed from rather high grade metamorphism of the oxide protore; the mineral occurs with hausmannite. In areas where the grade of metamorphism is in the greenschist facies, neither hausmannite nor jacobsite are found. The magnetic properties of jacobsite facilitate prospecting by magnetic methods. RIBEIRO discussed at some length the mineralogical characteristics of the jacobsites found in the Urandi district; one slide showed native copper with jacobsite.

JOHN VAN N. DORR, II, of the U. S. Geoolgical Survey, discussed the relation between the different facies of Precambrian iron-formation in Brazil and the different facies of associated manganese deposits. He pointed out that oxide-facies manganiferous formations in Brazil are interstratified with oxide-facies iron-formation, which is by far the most abundant type of iron-formation in Brazil. Carbonate-facies and sulfide-facies iron-formation, on the other hand, do not contain interbedded manganiferous formation; manganiferous rocks that are possibly contemporary with carbonate-facies iron-formation are separated from the iron-formation in space, even though the carbonate-type manganese

formations contain large quantities of manganese, as in Amapá and the St. João del Rey and Lafiete areas.

DORR also discussed the unmetamorphosed Cambrian and Ordovician oxide-facies iron-formation in western Mato Grosso and eastern Bolivia, which contains very large quantities of primary high-grade manganese oxide interstratified with the banded oxide-facies iron-formation.

PROF. H. J. KOARK of Uppsala University discussed the Precambrian sedimentary manganese deposits of Sweden. These polymetamorphic deposits have a very complex mineralogy and all belong to the upper sedimentary series of the Svekofennian shield, in which they form imbricate zones. KOARK compared the best-studied deposits, Nyberget, Långban, and Ultevis, in considerable detail. The deposits are thought to be sedimentary-hydrothermal; some addition of material and much modification of the deposits probably has taken place during the later metamorphisms.

DR. JOHN VAN N. DORR, II
US Geological Survey,
Washington, D. C. 20 242, U. S. A

CONTENTS

Felelős kiadó: Dr. Grassely Gyula
70-3510 — Szegedi Nyomda

CONTENTS